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Technical Activities 1985

Center for Radiation Research

Chris E. Kuyatt, Director

U.S. DEPARTMENT OF COMMERCE
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National Measurement Laboratory
Center for Radiation Research
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary
National Bureau of Standards, Ernest Ambler, Director

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ABSTRACT

This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during Fiscal Year 1985 in the NBS Center for Radiation Research. These activities fall in the areas of atomic and plasma radiation, radiation physics, radiometric physics, radiation sources and instrumentation, ionizing radiation, and nuclear physics.

Key Words: Atomic radiation, ionizing radiation; measurement support; nuclear radiation; plasma radiation; radiation instrumentation, radiation measurements; radiation physics, radiation sources; radiometric physics.

INTRODUCTION

This report is a summary of the technical activities of the NBS Center for Radiation Research (CRR) for the period October 1, 1984 to September 30, 1985. The Center is one of four Centers in the National Measurement Laboratory.

The Center for Radiation Research develops and maintains the scientific competences and experimental facilities necessary to provide the Nation with a central basis for uniform physical measurements, measurement methodology, and measurement services in the areas of near infra-red radiation, optical (visible) radiation, ultraviolet radiation, and ionizing radiation (x rays, gamma rays, electrons, neutrons, radioactivity, etc.); provides government, industry, and the academic community with essential calibrations for field radiation measurements needed in such applied areas as nuclear power, lighting, solar measurements, aerospace, defense, color and appearance, health care, radiation processing, advanced laser development, and radiation protection for public safety; carries out research in order to develop improved radiation standards, new radiation measurement technology, and improved understanding of atomic, molecular, and nuclear radiation processes, and to elucidate the interaction of radiation and particles (electrons, neutrons, and ions) with inanimate and biological materials; collects, compiles, critically evaluates, and supplements the existing atomic, molecular, and nuclear data bases in order to meet the major demands of the Nation for such data; and participates in collaborative efforts with other NBS centers in the interdisciplinary applications of radiation.

The summary of activities is organized into six parts, one for each of the five Divisions in the Center: Atomic and Plasma Radiation, Radiation Physics, Radiometric Physics, Radiation Sources and Instrumentation, and Ionizing Radiation, and one for the Nuclear Physics Group. A major subgroup of the Ionizing Radiation Division is the Office of Radiation Measurement. Each organizational unit tells its own story in its own way. In general there is an introduction followed by a series of short reports on current activities, publications during the year, talks given, committee participation, and professional interactions.

A detailed table of contents has been provided to permit the reader to find those activities of greatest interest. To obtain more information about particular work, the reader should address the individual scientists or their division, c/o Center for Radiation Research, Radiation Physics Building, C229, National Bureau of Standards, Gaithersburg, MD 20899.

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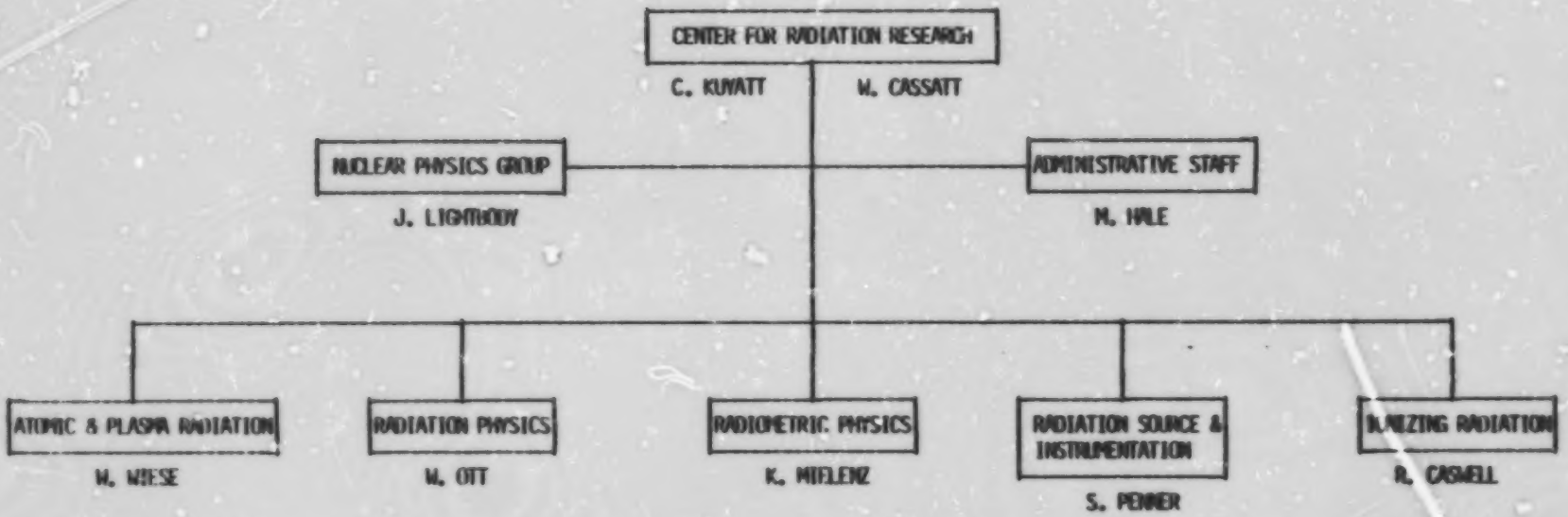

- ATOMIC SPECTROSCOPY
  W. Martin
- ATOMIC RADIATION DATA
  A. Weiss
- PLASMA RADIATION
  J. Roberts

- ELECTRON PHYSICS
  R. Celotta
- FAR UV PHYSICS
  R. Madden
  - SURF OPERATIONS
    G. Rakowsky

- SPECTRORADIOMETRY & OPTICAL PYROMETRY
  K. Mielenz, Acting
- SPECTROPHOTOMETRY
  J. Hsia
- PHOTODETECTOR PHYSICS AND METROLOGY
  J. Geist
- RADIOMETRIC MEASUREMENT SERVICES
  D. McSparron

- ACCELERATOR RESEARCH
  P. Debenham
- LINAC OPERATIONS
  J. Ordery
- ELECTRONIC INSTRUMENTATION
  J. Whittaker
- MECHANICAL INSTRUMENTATION
  D. Mohr

- OFFICE OF RADIATION MEASUREMENT
  E. Eisenhower
- RADIATION THEORY
  M. Berger
- RADIATION CHEM. & CHEM. DOSIMETRY
  M. Simic, Acting
- NEUTRON MEASUREMENTS & RESEARCH
  O. Wasson
- NEUTRON DOSIMETRY
  J. Grundl
- RADIOACTIVITY
  D. Hoppes
- X-RAY PHYSICS
  J. Motz
- ELECTRON & PHOTON DOSIMETRY
  R. Loevinger

TECHNICAL ACTIVITIES

Division 531, Atomic and Plasma Radiation

Task No. 15211 - Atomic Radiation Data and Standards

Task No. 15212 - Atomic Processes in Plasmas

The Atomic and Plasma Radiation Division carries out a broad range of experimental and theoretical research on atomic structure and atomic radiation in plasmas. The division determines a large variety of atomic radiation and collision data, encompassing wavelengths of spectral lines; atomic energy levels; ionization potentials; atomic transition probabilities; plasma line broadening parameters; ionization and excitation cross sections and rate coefficients, and dielectronic rate coefficients. Two data centers located in the division critically evaluate and compile atomic energy levels and transition probabilities. The division is also engaged in research on the interaction of atomic radiation with plasma environments, and it explores such effects for the development of new measurement techniques. Furthermore, well-defined atomic radiation sources are developed as VUV radiometric standards or wavelength standards.

These activities support several areas of science and technology. A good deal of our work ties into magnetic fusion research, where atomic data are needed for studies of the effects of heavy ion impurities and where atomic radiation processes are utilized as non-interfering plasma probes. Other areas of direct applications are parts of the Strategic Defense Initiative (SDI), vacuum ultraviolet and x-ray laser development, and space astronomy and solar physics. In all these areas, atomic radiation data are one of the basic ingredients, and plasma measurement techniques utilizing the emitted radiation are applied. Our vacuum ultraviolet radiometry work is now, for the first time, providing small calibrated radiation source packages to allow radiometric calibrations on board spacecraft, which are used, for example, on the space shuttle for accurate monitoring of the solar ultraviolet radiation, and are part of the space telescope instrumentation.

The division consists of three technical groups: Atomic Spectroscopy, Atomic Radiation Data, and the Plasma Radiation Groups. The division currently has 21 professional physicists, among them 18 Ph.D.s, plus 1 IPA. During 1985 the division has had 8 guest scientists from China (2), France, India, Germany (2), and Yugoslavia (2).

During the past year several of our projects again produced significant accomplishments, among them:

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Division 531, Technical Activities (cont'd.)

- the analysis of spectra of Ne-like highly stripped ions for x-ray laser research
- laser wavelength measurements with a computerized Fabry-Perot interferometer system at a precision of about 1 part in 10^9
- the convening of an atomic theory workshop on relativistic and QED effects to explore new directions in theoretical atomic physics
- the calculation of dielectronic recombination rates for Li, O, F, and Ne-like ions with the only comprehensive production code in existence anywhere
- first measurements of excitation rates for impurity ions with a tokamak device (TEXT tokamak)
- comprehensive tests and irradiance calibrations of special low intensity VUV sources for the faint object spectrograph on the Space telescope

These and others will be discussed in some detail in the following sections, where the principal work of the three technical groups during the last year is described.

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Division 531, Technical Activities (cont'd.)

1. Atomic Spectroscopy Group

(a) Highly Ionized Atoms--With the recent announcement by the Lawrence Livermore National Laboratory of an X-ray laser scheme based on Ne-like selenium transitions, a great deal of interest has arisen on spectral data of Ne-like spectra of highly stripped ions. We have, therefore, excited and identified n = 3-3 transitions in the Ne-like ions of Ca, Sc, Ti, and V. This work, carried out in collaboration with a Swedish group, also gives data of interest for plasma physics and astrophysics. In addition, we completed measurements and energy-level classifications for the spectra of the ten copper ions Cu^{11+} through Cu^{20+}. Similar spectra have been recorded for ions of Zn, Ga, Ge, and As, and will be analyzed soon.

We were able to identify lines of the Na-like ion Sr^{27+} in spectra of a laser-produced plasma. The identifications gave 26 energy levels of the ns, np, nd, nf and ng configurations. Comparisons of these results with calculations give significant tests of the accuracy of the theory for the Na isoelectronic sequence, including relativistic contributions.

We are making arrangements for experiments to obtain spectra of very highly ionized atoms using the OMEGA laser at Rochester. Our goal is to reach ionization stages of interest for the very high temperature fusion plasmas anticipated for the Princeton Tokamak Fusion Test Reactor and JET-Tokamak, as well as for x-ray laser physics (n=2 shell ions of atoms $Z \geq 38$).

(b) Wavelength Standards--We have measured the wavelengths of selected lines of singly ionized Hg^{198} with accuracies of a few parts in 10^7. These results allowed location of a basic Hg^+ two-photon transition in ion-trap research in Boulder and also give Ritz-type Hg^+ wavelength standards in the vacuum-ultraviolet region 90-200 nm. Our measurements of the spectrum of a platinum hollow-cathode discharge for the VUV and UV region 110-330 nm are almost complete. Wavelengths for almost 3000 transitions have been determined with uncertainties of ±0.0002 to ±0.0003 nm. These data will be used for on-board calibration of the high-resolution spectrograph for the Space Telescope and also provide standards for high-resolution laboratory spectroscopy. Our work giving new accurate Ritz-type standard wavelengths of Y^{5+} in the XUV region 20-40 nm has been completed. These wavelengths are derived from an extensive system of energy levels as obtained from a very complete analysis of this spectrum. Together with our previous Y^{3+} determinations and Y^{4+} work in progress, these wavelengths comprise a system of yttrium standards for the range 18-70 nm.

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(c) Atomic Photoabsorption in the XUV Region--A manuscript was completed on the Cs^+ absorption spectrum as observed through a Cs^+ plasma produced by laser pumping. We identified the $5p^5ns$ and $5p^5nd$ series both above and below the $5p^5\ ^2P_{3/2}$ ionization threshold ($5p^6\ ^1S_0 - 5p^5ns$, nd transitions, 50-60 nm region). An observed peculiar intensity behavior of these series below threshold was interpreted on the basis of a periodicity in the multichannel quantum-defect theory Lu-Fano plot.

We also extended our analysis of Ba^{2+} absorption to the below-threshold region to reveal channel interactions through intensity anomalies. This project is now almost completed.

A theoretical interpretation of photoabsorption in the 3d shell in the rare-earth elements Ce, Pr, Ho, and Er was completed. This work was done in collaboration with groups from the Free University of Berlin and from the Lawrence Berkeley Laboratory who obtained the data at the Stanford Synchrotron Radiation Laboratory.

(d) Laser Spectroscopy--We have previously demonstrated that laser wavelength measurements made with a Fabry-Perot interferometer illuminated with uncollimated (extended source) light are free of certain systematic errors difficult to eliminate from traveling-mirror wavemeters. We have now implemented computer acquisition of Fabry-Perot fringe patterns from a semiconductor array detector with real-time processing. Currently the patterns are analyzed at a rate of 1.4 Hz. Thermal drifts of the interferometer length are taken into account by alternately sampling the laser to be measured and a reference laser; thus the system makes a new determination of the unknown wavelength every 1.5 seconds. We have obtained a precision of 1 part in 10^9 for measurements of the reference laser against itself, averaged over 10 determinations. In initial tests an accuracy of better than 3 parts in 10^8 has been confirmed by measurements of (Doppler broadened) uranium lines that we had previously measured to this accuracy.

We are now progressing to use these new measurement techniques to make precise observations of Li Rydberg states by a Doppler-free three-photon technique. We have made preliminary observations of the 2s-3s two-photon transition and of a number of 2s-3s-np three-photon transitions. Further progress in this experiment has been temporarily delayed by difficulty in obtaining appropriate dye-laser optics. In the meantime we have used the apparatus developed for this experiment to study multiphoton "quasiresonant" ionization of Li at low laser powers. This effect has been observed using broad band dye lasers in other alkali metals and a number of possible mechanisms have been discussed. In Li we observe the effect with a single-mode laser and find strong dependence on the laser tuning at a resolution not obtainable with broad-band lasers. This suggests that we should be able to probe the details of the ionization mechanism, and experiments for this purpose are being prepared.

We are also investigating low-pressure electric discharges to find conditions giving minimal collisional transfer of atomic level excitations. Such discharges are needed for applications of double-resonance laser spectroscopic techniques to analyze complex atomic level structures.

(e) Atomic Energy Levels Data Center--We began a program of atomic spectral wavelength compilations with the most extensive compilation of data for (forbidden) magnetic dipole transitions ever carried out. The data include more than 1400 observed and predicted wavelengths for atoms and (mainly) ions of the elements B through Mo (Z=5-42) and also include calculated transition probabilities. These data tables, which are of great importance for plasma physics and astrophysics, now have been submitted for publication. We plan to compile allowed lines of many spectra with wavelengths and energy-level classifications based on our critical reviews of the analyses.

Our energy-level compilations for the 235 spectra of the iron-group elements K through Ni (Z=19-28) are finished and will be published soon as a new volume of atomic energy levels. A compilation for the 15 spectra of phosphorus has also been completed. We are now critically reviewing and compiling data on energy levels for the spectra of sulfur, chlorine, and molybdenum. The results of new calculations, theoretical interpretations, and even observations stimulated by our reviews are often included in our published compilations.

We monitor the literature on atomic energy levels, wavelengths, wavefunctions, etc., and the resulting reference files and published bibliographies are used by a wide clientele. The third supplement to our Bibliography on Atomic Energy Levels and Spectra, covering the literature from July 1979 through December 1983, was published this year.

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II. Atomic Radiation Data Group

The work of this group is entirely theoretical and consists of two major areas: (1) theoretical studies of atomic structure and processes, and (2) critical evaluation and compilation of atomic transition probability and spectral line shape data. The first activity involves the development of advanced theoretical methods and their implementation tc calculate atomic data. The main areas of activity have been dielectronic recombination, relativistic quantum mechanics, electron correlation, and radiative and collisional transition rates. The critical evaluation and compilation of transition probability and spectral line shape data takes place in the Data Center on Atomic Transition Probabilities, which also maintains an up-to-date bibliography of the literature in these fields.

(a) Theoretical Studies--One of the highlights of the year was an atomic theory workshop on relativistic and QED effects in heavy and highly ionized atoms, which we organized in collaboration with H. P. Kelly (University of Virginia) and L. Armstrong (Johns Hopkins University). The workshop was held at NBS in May of this year and was well attended, with over 60 participants from 3 continents. Our purpose was to identify the theoretical problems encountered in treating ultra-relativistic atomic systems and to establish stronger ties between the diverse theoretical approaches to computing properties of such systems. While the invited speakers covered a broad range of topics, the central question centered on the multi-electron aspects of the problem, as we hoped. The extended discussions were spirited and most participants participated with gusto. The proceedings will be published in the American Institute of Physics conference series.

We should note that the workshop served as the curtain raiser on a series of similar meetings held this past summer: a NATO Advanced Study Institute held in Corsica in June and a relativistic theory workshop held in Aspen in August, both with active participation of this group.

A large part of our work this year has been devoted to transferring, upgrading, and debugging programs for the new NBS class VI computer, the Cyber 205. This has involved a substantial investment of time to learn, not only the new system, but also the implementation of the vector capabilities of the machine as well. As of now, all of the atomic physics codes have been transferred, while the vector upgrading continues to occupy us.

The comprehensive production codes for computing dielectronic recombination rates have been used to compute total recombination rates for ions in the lithium, oxygen, fluorine, neon, and sodium isoelectronic

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sequences. These data have been provided to the Impurity Transport Monelling Group at the Princeton Plasma Physics laboratory, where we are consulting on a project to model the effects of atomic processes in heavy ion impurity transport. We are also using these programs in conjunction with structure codes to compute the detailed, and rich, dielectronic satellite line spectra of lithium-like ions. Intermediate coupling and configuration interaction are included, and individual wavelengths are estimated by referring calculated energies to the experimental levels of the parent lithium-like ion, a procedure which should incorporate most of the residual relativistic and correlation corrections.

Our studies of shell collapse, in collaboration with the Far UV Group of Division 533, have concentrated on singly ionized calcium, for which a comprehensive experiment has recently been completed. These are core-excited states involving a collapsed, or nearly collapsed, 3d electron. Preliminary calculations have included only outer shell correlations, but have clearly identified the low-lying excited states. Quantitative precision, however, is more difficult to obtain, because the shell collapse magnifies correlation corrections involving the 3p-shell, and this problem is currently under study.

During the past year, we hosted a number of leading atomic theorists at NBS. J. J. Desclaux (Grenoble) visited us in May to collaborate on developing computer programs for relativistic continuum wave functions for the Cyber 205 computer. These codes are essential for the calculation of relativistic excitation and ionization cross sections for heavy, highly stripped ions.

P. M. Mohr (Yale University) spent most of the month of August here studying the computational aspects of QED-related problems in atomic structure theory. A beginning has been made for including screening effects and realistic atomic models in the calculation of the Lamb shift for multi-electron atoms and ions.

G. Soff (GSI Darmstadt) also visited us in September to apply theoretical methods developed by Mohr (see above) to superheavy atoms created by heavy atom collisons in accelerator experiments.

(b) Data Center--Significant progress has been made on the design and development of computerized databases which will facilitate the storage, retrieval, and updating of critically evaluated numerical atomic spectroscopic data. Data elements pertinent to tables of energy levels, wavelengths, transition probabilities, and lifetimes have been identified and characterized; extensive documentation of requirements and specifications for energy-level tables has been completed, as well as partial documentation for tables of wavelengths and transition probabilities.

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Division 531, Technical Activities (cont'd.)

Compilations of atomic transition probability data continued for the spectra of the Fe-group elements scandium through nickel. Tabulations of allowed lines of neutral or weakly ionized atoms where the principal data sources are experimental have been completed, and work on the evaluation and compilation of data on forbidden lines of Fe-group elements is progressing.

Two critical reviews of Stark widths and shifts of spectral lines of both neutral and ionized atoms have been published in the Journal of Physical and Chemical Reference Data. A spectroscopic data book, which includes transition probabilities as well as energy levels and wavelengths, has been completed for the element Fe and has been published as a volume in the new Oak Ridge "Red Book" series on "Atomic Data for Controlled Fusion". Work is now being started on a second volume, which will contain data for the elements titanium and nickel. A compilation of spectroscopic data on titanium, including energy level diagrams and transition probability data, was completed in collaboration with several scientists from major Japanese fusion facilities. Also, we continue to supply in regular intervals bibliographical reference material for inclusion in the "International Bulletin on Atomic and Molecular Data for Fusion," which is published by the International Atomic Energy Agency (IAEA). Our input is their principal, and often only, source of spectroscopic references.

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III. Plasma Radiation Group

(a) Collisional Rate Coefficients with the 5CkJ Theta Pinch--A side arm port was installed on the theta pinch discharge tube, with the goal to measure the absolute excitation rates. However, this made the plasma unstable and the discharges became irreproducible. Many attempts were made to stabilize the discharge to obtain meaningful results but so far they have met with little success. However, relative excitation rates for the Ti X ion have already been measured and a publication is in preparation, comparing them with the detailed theoretical calculations of J. B. Mann of Los Alamos National Laboratory using the distorted wave method. We found that these Ti X excitation rates measured on the theta pinch are consistent with the results obtained on the TEXT Tokamak for copper ions in the same isoelectronic sequence. In these measurements the intensity calibration of the XUV spectrometers contributes the major part of the overall uncertainty. Lack of a portable VUV standard source for wavelengths below 600 Å for direct intensity comparisons is the main difficulty. So far, the common practice is to use the branching ratio technique in situ with the same plasma source generating the specific line radiation from light ions. However, the current high temperature plasma sources for fusion and x-ray lasers are unsuitable to produce low temperatures needed for the branching ratios to do an in situ calibration. Thus, we have been developing the commercially available Samson source as a portable VUV standard for calibrations with the branching ratio technique. We have successfully tested its stable operation producing the branching ratio lines in the visible (4619 Å) and VUV (209 Å) from N V for many hours. Also, we very recently completed a preliminary calibration of our 1m-grazing incidence spectrometer using the NBS SURF II radiometric source at these wavelengths. We plan to use this spectrometer as a transfer standard for future comparisons of calibrations.

(b) Tokamak Spectroscopy--Analysis of the n=3 and n=4 magnetic dipole transition wavelengths have yielded more than 50 new transitions in the Al-like through Cl-like ions of Ga through Y. This represents a thorough and systematic study of magnetic dipole transitions utilizing the TEXT Tokamak National Users Facility. These new measurements will allow the determination of the radial distributions of Doppler ion temperatures from a single impurity injection. Investigations of impurity transport in magnetic fusion devices will benefit from these observations because of the availability of many wavelengths in the visible spectral region, thus permitting remote instrument observations with optical fibers during deuterium-tritium operation.

Measurements of the absolute emission coefficients of spectral lines of Al-like and Cl-like Fe, Cu and Zn ions have been accomplished on the TEXT tokamak and analyzed. These observations were obtained using

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absolutely calibrated spectrometers in the XUV spectral region based on the branching ratio technique and SURF II. Measurements of the radial distributions of ion densities combined with these measurements yielded absolute excitation rates for these spectral lines for the first time on a tokamak.

(c) Autoionization in Electric Fields--We have recently observed autoionizing states in barium having high angular momentum non-penetrating orbitals. In collaboration with C. Clark of the Radiation Physics Division, we have developed a method to extract electric quadrupole moments and tensor polarizabilities of the atomic core from the fine structure splittings contained in our data. This method turns out to be quite general, and we have also applied it to previously existing data of isoelectronic series of halide-like ions. This has lead to the discovery that the quadrupole moment of these ions scales inversely with their charge, i.e. $\sim Z^{-1}$. This very useful result is not presently understood. Quadrupole moments for hydrogenic ions scale as Z^{-2}. One expects a deviation from this for other ions, but an exponent of $^{-1}$ is surprising indeed.

The above method, combined with our recently developed theory for field effects on oscillator strength distribution of resonances in the continuum, will allow us to compute spectra under the influence of external electric fields and compare them with our measured spectra.

(d) Calculation of Spectral Line Shapes of Ions in Plasmas--Last year, in collaboration with J. Cooper of JILA, we developed a formal theory for shifts of ion lines in plasmas. Currently we have undertaken a program to actually calculate the shifts and widths of hydrogenic and alkali-like ions in plasma conditions for x-ray laser experiments. We are doing quite rigorous calculations using close-coupled scattering methods, and at the same time we are developing "back of the envelope" approximation procedures to be used by the x-ray laser community in the near term. Line widths play a critical role in laser development, since they affect the gain exponentially.

(e) Vacuum Ultraviolet Radiometry with Plasmas--Three calibrations of the Space Telescope Optical Simulator (STOS) were performed in our laboratory for the purpose of calibrating the Faint Object Spectrograph (FOS) on the Space Telescope. The third calibration of the STOS utilizing five lamps as irradiance standards was completed early this year. This calibration covers the wavelength range from 120 to 800 nm. Three of these sources are low-powered (15W), rf-excited rare gas dimer lamps developed according to our recommendations. The other two sources are space-qualified Pt-Cr-Ne hollow cathode lamps. The FOS has been calibrated using the STOS and incorporated into the Space Telescope, which

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will be deployed in orbit by the Space Shuttle. We are now working on the calibration of a series of Pt-Cr-Ne and Pt-Ne hollow cathode lamps which will be used in throughput tests of the instruments on the Space Telescope as it is being prepared for deployment.

We have also performed further developmental work on VUV radiometric sources and published the results of our studies on a new monochromatic source of Lyman-α radiation. This source is valuable in that spectrally pure radiation can be obtained without the use of a monochromator. Further testing and refinement of the source are necessary for its establishment as a radiometric standard.

A very successful study of radiation from a laser-produced heavy-element plasma has been completed. The purpose was to investigate such a plasma as a far UV source, for use as an irradiance standard and as a background continuum source for absorption spectroscopy. Quantitative high-resolution spectra were taken of the radiation from nine target materials from 7 to 40 nm. Large differences are seen among the various targets; the data identifies those heavy elements (rare earths, etc.) most suitable for providing a clean, intense continuum at a given wavelength region. Measurements were also included on the effects of some parameters, such as laser energy, on the emitted radiation.

(f) Stark Broadening Shifts and Non-hydrogenic Ion Lines--We have continued our systematic observations of the Stark broadening of spectral lines in the homologous sequence of the rare gases and made further measurements of lines in the first and second ionization stages of Ne, Ar, Kr, and Xe. We have found irregularities in the line widths of spectral lines within the same multiplet or supermultiplet. While this is in disagreement with some published results, we believe our new data are more accurate, since they are very reproducible and are consistent over a range of plasma conditions. We can show that nearby perturbing levels causing additional broadening of some lines can lead to such irregularities. We have also observed the spectral line broadening and shifts in neutral nitrogen. The electron density of the plasma from these experiments was measured using a He-Ne laser quadrature interferometer. The temperature was measured utilizing the Boltzmann plot of the spectral line intensities of the ambient O II impurity.

We are currently setting up a new experiment for the observation of the width and shift of lithium-like beryllium lines. Beryllium will be introduced into the plasma by simply placing beryllium sheets into the discharge vessel or by laser ablation techniques. This work is a natural extension of our studies of the width and shift of He II lines.

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We have also continued our studies of the asymmetry patterns of plasma-broadened lines from neutral atoms, mainly carbon and argon. Since the asymmetries arise from ion broadening only, their isolation from the symmetrical Lorentzian profile, which is due to electron broadening, provides for the first time the opportunity to study both the effects of electron and ion broadening separately. Quantitative studies of the magnitude of the asymmetries--typically only one to three percent of the intensity at line maximum--have provided the first sensitive test of the quasi-static theory of ion broadening. We have found that the predicted theoretical line shapes are closely reproduced by the experiment and measured and calculated ion broadening parameters are in good agreement.

(g) Rayleigh Scattering and Redistributed Fluorescence--We have successfully made a near-resonance Rayleigh scattering measurement on a transient laser-driven barium plasma. The experimental results agree very well with the theoretical predictions for the regime where all line broadening except natural broadening is neglected. The plasma density obtained from the Rayleigh scattering measurement is about 10^{13} cm^{-3} and is consistent with an independent absorption measurement. We can also determine the collisional broadening of the plasma by doing Rayleigh scattering within the collisional width of the spectral line and by measuring the fluorescence caused by collisional redistribution. At the moment, we are improving the fluorescence detecting system to achieve a better spectral resolution and a better observing geometry. For the near future, we intend to do these measurements at much higher densities (10^{15} cm^{-3}) for more prominent collisional effects.

(h) Theory of Plasma Satellites--We have developed a theory to calculate profiles of plasma satellites in turbulent plasmas. This work is in collaboration with Prof. H.-J. Kunze of the Ruhr University, West Germany, where a plasma satellite fluorescence experiment is carried out. Preliminary calculations give very encouraging results for the helium (2P-4D, F) plasma satellite structures. Not only do they present a systematic picture of both plasma satellites (near and far), but they also take care of the forbidden transition and the second order plasma satellites.

We are now trying to extend the theory to a more generalized plasma turbulence spectrum for better understanding of the linkage between the plasma satellites and the plasma wave turbulence.

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SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 531, Atomic and Plasma Radiation

Yong-Ki Kim and Andrew Weiss organized an Atomic Theory Workshop on "Relativistic and QED Effects in Heavy Atoms" held at NBS, Gaithersburg, on May 23-24, 1985.

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INVITED TALKS

Division 531, Atomic and Plasma Radiation

Kim, Yong-Ki, "Energy and Angular Distributions of Secondary Electrons," Atomic Physics Seminar, University of Pittsburgh, Pittsburgh, Pennsylvania, March 22, 1985.

Reader, J. R., "Wavelengths from a Pt-Ne Hollow Cathode Lamp for Calibration of the High Resolution Spectrograph," Space Telescope Calibration Workshop, Johns Hopkins University, September 25, 1984.

Roszman, L. J., "Current Research on Dielectronic Recombination at NBS", Atomic Data Group of the Physics Department of Lawrence Livermore National Laboratory, February, 1985.

Roszman, L. J., "How Do Plasma Density and Fields Affect Dielectronic Recombination?", Fifth Topical Conference on Atomic Processes in High Temperature Plasma, APS, Pacific Grove, California, February 25-28, 1985.

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Wiese, W. L., "Ion Broadening Effects in Plasmas," Fudan University, Shanghai, Peoples Republic of China, October 29, 1985.

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Wiese, W. L., "Stark Broadening of Heavy Elements," Kyoto University, Kyoto, Japan, November 10, 1984.

Wiese, W. L., "Spectroscopic Data and VUV Standards for Magnetic Fusion Research," U.S.-Japan Seminar on Tokamak Diagnostics by VUV and X-ray Spectroscopy, Nagoya University, Nagoya, Japan, November 15, 1984.

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PUBLICATIONS IN PREPARATION

Division 531, Atomic and Plasma Radiation

Brewer, L. R., Ligare, M. and Kelleher, D. E., Four Photon Resonance Enhanced Ionization of Atomic Hydrogen and Threshold (in preparation).

Clark, Charles W., and Kelleher, D. E., Quadrupole Moments and Tensor Polarizabilities from Fine Structure Splittings of Non-Penetrating Orbitals (in preparation).

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Mishin, V. I., Lombardi, G., and Kelleher, D. E., Electric Field Effects in Autoionizing States in Gadolinium (submitted).

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Pittman, T. L. and Fleurier, C., Plasma Shifts of the He II H_α and P_α Lines. Phys. Rev. A (submitted).

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Roszman, L. J., The dielectronic recombination rates for some ions of the lithium isoelectronic sequence (in preparation).

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Sansonetti, Craig J. and Andrew, Kenneth L., The Spectrum and Energy Levels of Singly Ionized Cesium: I. Revision and Extension of the Cs II Energy Levels (submitted).

Sansonetti, C. J. and Weber, K.-H., Precise measurements of Doppler-free two-photon transitions in Rb: A reevaluation of suggested dye laser reference wavelengths (in preparation).

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TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 531, Atomic and Plasma Radiation Division

Daniel E. Kelleher

Member, International Organizing Committee of the Conference on Spectral Line Shapes.

Yong-Ki Kim

Member of Program Committee, APS Topical Conference on High Temperature Plasmas.

Georgia Martin

Chairperson, NAS/NRC Committee on Line Spectra of the Elements - Atomic Spectroscopy.

William C. Martin

Chairman, Working Group on Structure of Atomic Spectra, International Astronomical Union.

Member, IAEA Network of Atomic Data Centers for Fusion.

James R. Roberts

Member of TEXT Users Organization.

Jack Sugar

Member, OSA Meggers Award Committee.

Member, NAS/NRC Committee on Line Spectra of the Elements - Atomic Spectroscopy.

Wolfgang L. Wiese

Member of Organizing Committee, International Astronomical Union, Commision on Fundamental Spectroscopic Data.

Chairman, Working Group on Atomic Transition Probabilities, International Astronomical Union, Commission 14.

Member, IAEA network of Atomic Data Centers for Fusion.

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Division 531, Technical and Professional Committee Participation and Leadership (cont'd.)

Wolfgang L. Wiese

Member, OSA Meggers Award Committee.

Co-Chairman, US-Japan Workshop on "Tokamak Diagnostics by Visible, VUV and X-ray Radiation," Nagoya, Japan.

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MAJOR CONSULTING AND ADVISORY SERVICES

Division 531, Atomic and Plasma Radiation

1. The Data Centers on Atomic Energy Levels and Transition Probabilities routinely fill requests for atomic data or literature information submitted by scientists in a wide range of research areas. The requests average about 30 per month. On occasion, special reports are prepared for particular user groups. Thus, W. C. Martin and W. L. Wiese write updates on atomic data of interest for the astrophysical community for the IAU Transactions, and give review reports at the General Assemblies of the International Astronomical Union.

2. J. M. Bridges has consulted with staff of Ball Aerospace, Boulder, CO, concerning use of standard sources in calibration of instruments for UV measurements in space.

3. Y.-K. Kim serves as a consultant to the A Division of the Lawrence Livermore Laboratory on x-ray laser development.

4. Kim has also consulted with the Princeton Plasma Physics Laboratory on the role of atomic processes in plasma cooling. This led to a reassessment of the role of neutral hydrogen atoms in fusion reactors being designed under the INTOR program.

5. J. Z. Klose performed numerous tests and calibrations of three Pt-Ne and two Pt-Cr-Ne hollow cathode lamps this year as part of contract work with Martin Marietta Aerospace. His work involved close consultation with Martin Marietta personnel concerning the results of each test and plans for successive tests and calibrations.

6. W. C. Martin and J. Reader have consulted and advised NASA scientists and other astronomers on standard wavelengths for calibration of the High-Resolution Spectrograph for the Space Telescope, and Reader has also advised on and assisted with tests of the large echelle grating for this instrument.

7. J. R. Roberts serves as a member of the TEXT Users Organization (TUO). TEXT stands for Texas Experimental Tokamak and is a national plasma users facility. The TUO steering committee considers the special needs of off-site user groups and has provided advice and perspective on the users program to the TEXT managers and the Office of Fusion Energy at DOE.

8. L. J. Roszman provided consulting activities on various electron-ion collision processes and high density plasma modeling for x-ray laser

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research and development in the Lawrence Livermore National Laboratory A and Physics Divisions.

9. L. J. Roszman advises and consults with the Impurity Transport Modeling Group of the Princeton Physics Laboratory on electron-ion collision processes and other atomic data as well as the modeling of low density plasmas.

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JOURNAL EDITORSHIPS

Division 531, Atomic and Plasma Radiation

J. Reader, Editor, Line Spectra of the Elements, Handbook of Chemistry and Physics, CRC Press.

W. L. Wiese, Associate Editor, Journal of Quantitative Spectroscopy and Radiation Transfer.

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TRIPS SPONSORED BY OTHERS

Division 531, Atomic and Plasma Radiation

Y.-K. Kim traveled to the University of Pittsburgh, Pittsburgh, Pennsylvania for discussions with their atomic physics group and to give an invited talk. The trip was paid for by the University of Pittsburgh (March 1985).

L. J. Roszman traveled twice to the Lawrence Livermore Laboratories in California as a consultant with an R-Program group led by Dr. S. Younger. Both trips were paid for by LLNL (February, July 1985).

L. J. Roszman traveled twice to the Princeton Plasma Physics Laboratory as a consultant. Both trips were paid for by PPPL (June, July 1985).

T. A. Nee spent three months at the Institut für Experimentalphysik V, Ruhr University Bochum, West Germany, to attend their plasma diagnostics programs. Most of the expenses were paid by the Sonderforschungsbereich Plasmaphysik Bochum/Jülich (October-December 1984).

W. L. Wiese gave several invited talks and lectures at Fudan University, Shanghai and Jilin University, Changchun during the period October 28-November 8, 1984. All expenses in China were paid by the Chinese host organizations.

W. L. Wiese traveled to Dubrovnik, Belgrade, and Zagreb, Yugoslavia. He attended the Boris Kidric Institute seminar in Belgrade and reviewed ongoing projects under the NBS-Yugoslav Cooperative S&T Program at Belgrade University and Institute of Zagreb. Airfare was paid by the US-Yugoslav Joint Board (June 1985).

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CALIBRATION SERVICES PERFORMED

Division 531, Atomic and Plasma Radiation

Type of Service	Customer	SP 250	No. of Tests	Income
Hollow Cathode Lamp	Martin Marietta	Contract	10	$37k
Argon Arc	NOAA	Contract	1	2k
Argon Arc	EG & G	7.6B	1	1.8k
Argon Arc	Physical Res. Lab. Ahmedabad, India	7.6C	1	1.8k
Argon Arc	Changchun Inst. of Optics, China	7.6C	1	1.8k
Deuterium Lamp	General Electric	7.6D	1	1k
Deuterium Lamp	Aerojet Electrosystems	7.6D	1	0.6k

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SPONSORED SEMINARS AND COLLOQUIA

Division 531, Atomic and Plasma Radiation

Byron A. Palmer, Los Alamos National Laboratory, "The Los Alamos High-Resolution Fourier Transform Spectrometer", October 5, 1984.

Thomas Gallagher, University of Virginia, "Laser Spectroscopy of Autoionizing Rydberg States", March 14, 1985.

K. T. Lu, Atomic and Plasma Radiation Division, "The Fermi-Segre Formula Revisited: On the Study of the Ion-Core by Rydberg Electrons", April 17, 1985.

Nikola Konjevit, Institute of Physics, Beograd Yugoslavia, "Stark Broadening of Helium Lines in a Dense Cool Plasma", April 24, 1985.

Chris Cromer, Atomic and Plasma Radiation Division, "A New, Intuitive Approach to MQDT", May 15, 1985.

Rene Beigang, Free University of Berlin, "High Resolution Laser Spectroscopy of Rydberg States with Principal Quantum Numbers N > 100", May 22, 1985.

Alexander Piel, Institut fur Experimentalphysik, Ruhr University, Bochum, West Germany, "Ion Dynamic Effects for Plasma Broadened Helium Lines", May 31, 1985.

Alfred Müller, JILA and University of Giessen, West Germany, "Electron-Impact Ionization of Ions with Comments on Recent Dielectronic Recombination Experiment at JILA", July 1, 1985.

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TECHNICAL ACTIVITIES

Division 533, Radiation Physics

Task No. 15233 - Far UV Radiometry
Task No. 15234 - Far UV Measurements
Task No. 15235 - Electron Physics Research

The Radiation Physics Division focuses on measurement programs relating to the use of electron, laser, ultraviolet, and soft x-ray radiation in the energy range from about 5 eV (250 nm) to 300 eV (4 nm).

In support of this mission, radiation standards and advanced measurement techniques are developed. Through our standards program, the Division provides the central national basis for the measurement of far ultraviolet and soft x-ray radiation. The NBS synchrotron radiation facility and a detector calibration facility based upon well-characterized photoionization chambers serve as national radiation standards. Measurement services are available for the calibration of the quantum efficiency of UV photodiodes and the spectral responsivity of vacuum ultraviolet spectrometer systems.

Through our electron measurements program, new types of electron sources and detectors are developed to investigate the properties of matter on an atomic scale. For example, specially designed spin-polarized electron sources and detectors are used to determine fundamental atomic scattering properties and to measure surface magnetism. An electron tunneling device is being developed to provide "images" of surfaces on an atomic scale and to study relationships between macroscopic material properties and surface microstructure.

With the goals of improving standards and understanding the fundamental physical phenomena upon which they are based, the Division also conducts theoretical and experimental research on the electronic structure of atomic and molecular systems, the interaction of the systems with photon and electrons, and radiation deposition and energy transfer processes. Theories are developed for the scattering and transport of electrons in materials of fundamental and technological interest. New techniques and instrumentation are developed to study radiative reactions with matter, including photoexcitation and photoionization processes and non-linear effects in intense laser fields. Studies are underway to investigate to what extent the properties and behavior of atomic systems

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can be manipulated by measuring and controlling atomic and molecular states in their local environment.

The division has two major research facilities, a dedicated synchrotron ultraviolet radiaton facility (SURF II) and a polarized electron research facility.

SURF II is a dedicated synchrotron radiation facility, consisting of a 280 MeV electron storage ring, a 10 MeV microtron injector, and associated synchrotron radiation beam lines. It produces light in a narrow, intense, highly polarized beam with a continuous and accurately known spectrum from the infrared through the visible and into the far ultraviolet. SURF II is unique among synchrotron light sources by virtue of its uniform and precisely known circular orbit. This allows accurate determination of all the spectral and geometrical properties of the radiation and hence its use as an absolute radiometric standard.

This facility serves staff from our own division, users from other NBS divisions, and outside users in radiometric standards and calibration work, optical physics research, surface science, biochemistry, spectroscopy, and other research areas utilizing far ultraviolet radiation. It fills a growing demand for radiation in the ultraviolet and soft x-ray region of the electromagnetic spectrum. Of the 11 light ports at SURF, 6 are now instrumented for user applications and for calibration of optical instruments and transfer standard photodiodes. Some of these ports are shared by more than one experimental station. Three of the remaining ports are utilized for beam current monitoring, electron counting, and machine diagnostics. Most experiments and calibrations can run simultaneously, unless they require special beam parameters.

The polarized electron scattering facility is used to produce and measure beams of spin polarized electrons and is available for collaborative research by NBS and outside scientists in areas of mutual interest on a time-available basis. Three separate, ultra-high vacuum instruments are available. The polarized electron beams have currents in excess of 1 μA, with an optically reversible polarization at energies less than 1 KeV and with an energy resolution of ≈0.15 eV.

These electrons are used to probe spin dependent scattering interactions between polarized electrons and surfaces or polarized electrons and atoms. The electron-surface scattering capability can be used to determine surface structure or study surface magnetic phenomena and their dependence on temperature, composition, adsorption, etc. The electron-atom scattering capability can be used to probe spin-orbit and exchange interactions in electron scattering and to completely determine the parameters of a selected collision process. In a new research

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direction, special electron spin detectors can be used in combination with a scanning electron microscope to constitute an electron polarization microscope that can probe magnetic structure on a sub-micron scale.

As can be seen in the following sections, the division staff has been active in publishing research papers, providing calibration services, presenting invited talks, sponsoring conferences, providing consultation services, and participating in technical and professional committees. We have also been very active in technical collaborations within NBS and with universities, industry, and other government agencies. Highlights of the past year include:

1. A fundamental theory was developed to explain the spin-polarization of secondary electrons emitted from magnetic materials, a phenomenon first measured here and now being exploited by us to enable measurements of surface magnetism and magnetic microstructure.

2. A spin-polarized, scanning electron microscope has been demonstrated by modifying a UHV-SEM with a newly developed polarized-electron detector system. Initial measurements were made of an $Fe_{97}Si_3$ crystal with magnifications of x500 to x10,000 and showed that both physical and magnetic microstructure could be simultaneously measured.

3. An enhanced program on Scanning Electron Microscopy with Polarized Electron Analysis (SEMPA) was planned with the assistance and support of the Director's office. Elements of the plan include: (1) public information announcements; (2) a briefing to the NBS Visiting Committee; (3) an assessment of industrial needs for measurements of magnetic microstructure; (4) purchase of a new UHV-SEM; and (5) soliciting funding support and cooperative research with industry.

4. Fundamental measurements that are stimulating a new area of theoretical and experimental atomic collisions research were made in a series of polarized electron-polarized atom, state-selected scattering experiments. For the first time, electron exchange effects were directly measured in super-elastic electron-atom scattering.

5. A workshop on "Atomic Spectra and Collisons in External Fields" was held at NBS on October 22 and 23. It attracted about 88 participants. Its purpose was to discuss recent work on highly excited atoms in electric and magnetic fields.

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6. A new data evaluation project on Soft X-Ray Interactions with Matter was funded by SRD and DOE and initiated in collaboration with the Ionizing Radiation Division.

7. A new record stored beam current of 200 mA at full operating energy of 284 MeV was achieved at SURF, almost twice as much as last year's record current and about 20 times higher than the design level.

8. Major new areas of research activity were started at SURF:

   - new high flux surface science beam line was constructed.

   - new soft x-ray fluorescence experiment is on-line, in collaboration with U. of Tennessee and ORNL.

   - new photoionization experiment utilizing fluorescence spectroscopy is on-line.

   - new beam line has been built up for extremely high resolution atomic and molecular spectroscopy, in collaboration with U. of Maryland and NRL and with the support of NSF.

   - new detector calibration beam line is in operation.

   - first results were obtained from the new high resolution photoelectron spectrometry facility (ARPES).

9. A major, new radiometric intercomparison of SURF and standard lamps was successfully carried out in the near ultraviolet through an industrial research associate arrangement with H. Kostkowski, assisted by a visiting scientist from NOAA and staff from divisions 531, 533, and 534.

10. A new collaboration between the Far UV Physics staff and staff from LANL was planned to enable complementary and coordinated photoionization studies to be done at Brookhaven/NSLS and NBS/SURF.

11. A plan was presented by R. Madden to the Director's office for obtaining funding for a SURF upgrade from NBS and a consortium of other agencies, viz, DOE and NSF. The goal is to provide sufficient capabilities for SURF to be a national synchrotron user's facility.

12. For the second year in a row, work in the Division is being recognized with an IR-100 award (Celotta, Pierce, Feigerle, and Seiler: A New High Current Monoenergetic Electron Gun).

FAR UV PHYSICS GROUP

The Far UV Physics Group is characterized by the development of radiometric techniques and standards for far ultraviolet radiation and by research on measurement methods utilizing far ultraviolet radiation. Use is made of the NBS synchrotron ultraviolet radiation facility (SURF II), as well as other synchrotron radiation facilities (Orsay, Brookhaven), to investigate the fundamental interactions of photons with atoms and molecules and to establish a basis for radiometric standards and spectrometer sensitivity measurements in the far ultraviolet. Additionally, off-SURF experimental and theoretical research is carried out to study multiphoton effects in laser-excited and laser-ionized materials, and to investigate fundamental fragmentation processes in organic molecules.

SURF Operations and Improvements

SURF II performance took another quantum leap upward this year when a record beam current of 200 mA was achieved on June 4, 1985. This current was nearly double the 103 mA record of June 13, 1984. In fact, stored beam currents exceeding 100 mA were routinely achieved from April through July 1985. This improvement was due to a new, commercially-developed cathode utilizing oriented single-crystal lanthanium hexaboride as the emitter. Such cathodes were first made for scanning electron microscopes, but this is the first known application in an accelerator. The microtron injector is now performing very near its design limit, routinely delivering 60 mA at 10 MeV, nearly double the peak currents obtained in the past with polycrystalline LaB_6 cathodes. The commerical cathodes also exhibit excellent long-term stability and longevity, resulting in higher average beam intensities and reduced downtime.

The usefulness of the high stored currents has been limited by rather poor beam lifetime at 280 MeV. This is because the 2 kW RF power supply, originally designed for 240 MeV, is marginal at the higher energy. A new 5 kW system is now being commissioned. It should not only improve substantially the beam lifetime at 280 MeV, but have enough reserve capacity to allow operation up to 300 MeV.

In preparation for the new RF system, the old RF output cable was replaced with a low-loss coaxial transmission line. This change alone resulted in 10% higher cavity voltage and a noticeable improvement in beam lifetime at 280 MeV. A second effect of the low-loss line appears to be

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stronger interaction between the stored beam and the amplifier output impedance. Longitudinal bunch oscillations are now more violent than before, especially at lower energies while ramping. As expected, this interaction also depends on line length and is strongest when the line is near an integral number of half-wavelengths long. We have recently been able to raise the threshold of the longitudinal oscillations from 19 mA to over 90 mA by trimming the line length. The stabilized beam exhibits much better lifetime than an oscillating one. We are now studying the contributions to beam lifetime and stability of: (a) transmission line length; (b) line attenuation; (c) cavity voltage; and (d) amplifier impedance.

Further study is needed to determine if proper tuning of these elements can passively stabilize beam currents of 200 mA or more, over the full energy range from 10 to 300 MeV. An electronic phase shifter of suitable frequency and bandwidth is also available to try stabilization by phase feedback. If the bunch oscillations can be controlled, stacking of multiple injections may still be possible. In that case the upper limit for SURF beam intensity may be even higher than the present maximum of 200 mA.

It has also become clear that modification of bunch length (to improve beam lifetime) by the use of a higher harmonic RF cavity will not be successful unless the beam is first stabilized. Work on the harmonic RF system has therefore been temporarily sidelined until the stability problem is solved.

In the course of studying the oscillations, SURF operations staff made a significant contribution to the understanding of a class of beam instabilities in storage rings, referred to in the literature as "slow fluctuation". This type of instability was shown to be a relaxation oscillation in which intervals of longitudinal oscillation alternate with (usually) longer, oscillation-free intervals. The oscillation in SURF is simple dipole-mode (rigid bunch) phase oscillation which grows in amplitude until non-linear restoring forces introduce sufficient frequency spread among particles that coherence is lost and oscillation closes. The oscillation-free interval is dominated by radiation damping, so its duration is strongly energy-dependent. A simple phase modulation model of the dipole-mode oscillation was adapted from communication theory. This model accurately predicts the strengths of the RF harmonics and modulation sidebands observed on the beam current by a spectrum analyzer. It also predicts a negative feedback mechanism that may help explain the observed stabilization and self-limiting of oscillations. These studies were reported at the 1985 Particle Accelerator Conference.

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New High Energy Capability at SURF

The success of our programs utilizing the high-flux normal-incidence monochromator has led us to proceed with the extension of our capabilities to shorter wavelengths. We have installed a new high-throughput grazing-incidence monochromator for SURF-II. This instrument uses SURF's orbiting electron beam as its entrance slit--thus taking advantage of SURF's small vertical beam size and high brightness. The grating is placed as close as possible to the orbit and intercepts 51 mrad of horizontal orbit and (for wavelengths below 500A) the full vertical radiation output. Using three independently optimized gratings, the monochromator will cover the 30-600 A spectral range. The first grating has been characterized and provides ~10^{10} photons per second per milliamp of ring current at the peak of its intensity curve. With a typical 100 ma stored current, ~10^{12} photons per second are delivered to the sample. Larger exit slits can increase this by a factor of 4 with some decrease in resolution. The range of the present grating is 17 to 90 eV.

The new monochromator will allow us to extend our programs in surface science, ultraviolet photoemission spectroscopy, and gas-phase angle-resolved photoelectron spectroscopy to higher photon energies. Two stages of differential pumping are provided between the experimental chamber and the monochromator so that gas phase experiments should be able to operate with relatively high source pressures. Additional gratings are being manufactured which will reduce 2nd order light and extend the range to ~180 eV photon energy.

Angle-Resolved Photoelectron Spectroscopy

A long successful run at SURF has been completed utilizing our high resolution angle-resolved photoelectron spectrometer. This run stretched over a 14-month period during which studies on N_2, H_2, CO_2, and NO were completed. These studies utilized the angle-resolved capability of the photoelectron spectrometer system to elucidate the mechanism of resonance processes in molecular photoionization. The resonance processes, autoionization and shape resonances, play a central role in photoionization of valence shell electrons. This study therefore affords a window into the mechanisms of electron correlation in molecules.

The two spectrometers of the instrument are now being outfitted with multichannel array, position-sensitive detectors. These devices, along with appropriate software improvements, will provide at least a factor of ten improvement in electron signal with a corresponding gain in the basic sensitivity of the instrument. These improvements will permit new and novel experimental programs.

This program is a collaboration between NBS and staff at Argonne National Laboratory and Los Alamos National Laboratory.

Polarized Fluorescence Studies

A series of studies has been carried out at SURF using the polarization of the synchrotron radiation beam as a probe of molecular autoionization. These studies showed that the polarization of the fluorescence from excited states is a direct probe of the photoionization dynamics and of the symmetry signatures of autoionization resonances. The modification of the original apparatus has been completed. A new optical bench has been constructed to more fully exploit the high flux capabilities at SURF.

We now have the capabilities to do the following:

(a) study polarized fluorescence from molecular gases;

(b) study wavelength-dispersed fluorescence from molecular systems - the high brightness of SURF is especially important for these measurements;

(c) study threshold shifts induced by external electric fields at photon energies above the ionization threshold.

First measurements with the new apparatus at SURF are in progress. We are concentrating on oxygen. The study of shape resonance effects in water vapor are also planned for the current running time at SURF. In collaboration with staff from Howard University, we are seeking support for experiments to derive the heat of formation of important atmospheric species by observing the fluorescence of dissociative products.

Soft X-Ray Spectroscopy Using Synchrotron Light Excitation

This program is a study, by means of soft x-ray emission spectroscopy, of fragile compounds that are easily damaged by electron beam irradiation. The construction of the high sensitivity soft x-ray spectrometer is being funded by an NSF grant to the University of Tennessee. The spectrometer was finished during the summer. After initial testing at the University of Tennessee, the hardware was installed at SURF-II for an extended run. First results on the silicon $L_{2,3}$ emission band were obtained at SURF, in collaboration with the Semiconductor Materials and Processes Division. We expect to move the gear to Brookhaven National Laboratory during the winter of 1985. Initial work there will be to study the emission spectra of systems of interest to material scientists. We are proposing to study boundaries and interfaces in silicon compounds and other systems of

importance in the fabrication of semiconductor devices. Another area that we are proposing to investigate is the emission spectra of the solid inert gases, their alloys, and impurities embedded in the rare gas matrix. This program is a collaboration between the University of Tennessee, Oak Ridge National Laboratory, and NBS.

Laser Prepared States

A new class of experiments is being planned for SURF which will utilize both lasers and synchrotron radiation. We have purchased an argon-ion pump laser and now are requesting funds to purchase the broadly tunable ring dye laser. The new hardware for the polarized fluorescence experiment will be adaptable to these experiments as will be the high resolution photoelectron spectrometer.

In the interim it has been possible to continue a collaborative research program at LURE in Orsay, France. This experiment consists of a toroidal grating monochromator connected to the ACO storage ring at LURE, and a ring dye laser stabilized to 20 MHz bandwidth and used to pump ground state atoms to excited states in the atomic vapor. The output of the monochromator and the laser intersect at right angles in the sensitive volume of the electron spectrometer. An effusive beam of metal vapor intersects these photon beams and the photoelectrons produced in the interaction zone are detected in the electron energy analyzer.

This year we have been able to accomplish several major goals:

a) We have measured the oscillator strength of autoionizing resonances in sodium produced by transitions of the type $2p^6 3p \rightarrow 2p^5(2p_{3/2,1/2})3s3p(^{1,3}P)$. A letter describing these results has been accepted for publication.

b) We have measured the partial photoionization cross section of the 5d electron in laser-excited barium vapor over a broad energy range (18 eV to 150 eV). Autoionizing structure involving the excitation of a 5p electron in the presence of an outer electron excited to a 5d orbital has also been observed for the first time.

c) A book chapter is being prepared for Advances in Atomic Physics, reviewing photoionization from excited atoms.

In addition to scientists from SURF and LURE, researchers from the Laboratoire Aime Cotton, the Service de Physique des Atoms et des Surfaces, CEN/Saclay, and SUNY-Stony Brook collaborated in this work.

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Development of a Measurement Program to Use the Time Structure of the Electron Beam at SURF

As a future project we are undertaking the development of a program which makes use of the time structure of the beam at SURF. Many important phenomena take place on a time scale between 10^{-9} and 10^{-13} second. For example, typical chemical reactions and molecular vibration times are in this time domain. In fact there is a whole new research area devoted to studying phenomena occurring on the picosecond time scale. Lasers are ideally suited for this work. Unfortunately, conventional lasers do not yet probe the VUV spectral range, and the lasers that do have such high power that they often damage the specimen under study and only yield the same number of photons/sec that one could obtain with synchrotron radiation. Synchrotron radiation is a source of pulsed VUV radiation that gently produces the excitation where chemical reactions can be easily induced. Once this sample of excited molecules is produced, it can be synchronously probed by a laser locked to the storage ring frequency.

The first step in this program is a study of the SURF electron bunch profile and its stability. During the past year improvements to the RF system have greatly improved the stability of the beam and reduced its harmonic content. The next step in these experiments is to make simple experiments to further test the feasibility of using SURF for these experiments.

Surface Science

We have supported at SURF the establishment by the NBS Surface Science Division of an experimental capability to study adsorbed molecules on surfaces. These studies use several SURF monochromators and an ultrahigh vacuum system. Photon stimulated desorption (PSD) of ions is being studied to understand the desorption mechanisms and energetics. Variable wavelength ultraviolet photoemission spectroscopy (UPS) is also utilized to characterize the surface species formed upon adsorption of the molecules on clean metal and oxide substrates. Ion desorption mechanisms for ionically and covalently bonded adsorbates are investigated.

Two important studies were completed last year. The first was a study of PSD from a single crystal of TiO_2. This compound is used as a model system for the theory of Auger-stimulated desorption. It was found that ions desorb more readily from a defect surface than from the nearly perfect surface. This is contrary to what current theory predicts and shows the competition between electronic state and geometrical structure. The reduced coordination of the oxygen atom with the Ti cation gives an enhanced ion yield and shows the importance of geometry in the desorption probability.

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The second study involved orientation of CO adsorbed on a Cr(110) surface. It was found that at low coverage the CO either lies flat or at a very inclined angle to the surface. The UPS study verified the first observation of inclined CO on a metal surface. At higher coverages or with coadsorption with oxygen, the CO stands upright. Presently, photon stimulated ion desorption from the inclined or upright CO is being studied.

Very High Resolution Spectroscopy at SURF

The National Science Foundation is partially supporting the installation of a very high resolution, 6.65 m normal-incidence spectrometer at SURF. The goal of this project is to do research on the dynamics of energy transfer in atoms and molecules with an energy resolution that is a factor of 10 better than photometric instruments existing presently at synchrotron radiation facilities. In a collaborative effort, a similar instrument is being installed and converted to photometric studies at the KEK Photon Factory in Japan. These instruments will cover the 300-2000A spectral range with resolving powers of 2×10^5. In addition, our instrument will provide highly polarized radiation (polarization > 98% for $\lambda > 600$ Å).

This instrument is now installed at SURF. The beam line and its optics have been commissioned. Polarization studies of the collection optics have been completed and commissioning of the spectrometer was begun by the University of Maryland and NRL staff in September 1985. The University of Maryland and NRL staff are the principle investigators on this program. SURF staff are contributing support to the project. Expected NBS users are from the Centers of Radiation Research, Basic Standards, and Chemical Physics. Outside users expressing interest in using this facility are from NRL, Univ. of Maryland, ORNL, Yale, Argonne, SUNY Binghamton, Ohio State, Univ. of Nebraska, Harvard College Observatory, and Imperial College.

Electric Field Effects

This program studies the effect of electric fields on the absorption cross sections of atoms and molecules at high photon energies. It will be carried out, in the future, on the new 6.65 m high-resolution spectrometer beam line. A cryopump-based, vacuum/gas handling system has been completed to support these studies. We are beginning a series of measurements to characterize the intensity and polarization of the radiation coming down the new beam line.

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While waiting for the high-resolution spectrometer to be ready, we have carried out a study of the effect of electric fields on autoionizing Ba states in an off-SURF experiment. These studies are made using three dye laser excitation to reach odd parity states and two dye laser excitation to reach even parity states. An example of the results observed is the effect of an electric field on the $5d9p\,^3P_1^\circ$ barium resonance above the first ionization threshold. This relatively broad odd parity autoionizing level is nearly degenerate with a much narrower even parity level. At moderate fields the sharp level produces an interference dip in the broad level. At higher fields the interference eventually gives rise to two split components. The effects on both even and odd parity levels were observed and explained with a nonperturbative theory. Effects of the electric field (with values up to 105 kV/cm) were observed in other spectral regions of Ba. We are in the process of analyzing these results.

This work is a collaboration among SURF staff, the Atomic and Plasma Radiation Division, and the Center for Basic Standards.

Photoabsorption of Laser-Ionized Species

The new time-resolved VUV absorption spectrometer, recognized with a 1984 IR-100 award from Research and Development magazine, is performing exceedingly well. This year, in collaboration with Prof. B. Sonntag of the University of Hamburg, we have obtained the first 3d photoabsorption spectrum of laser-excited calcium (Ca: $4s4p\ ^3P_1$) and laser-ionized calcium (Ca: $4s\ ^2S$). Comparisons of these spectra with that of the neutral ground state show some striking differences which we hope will shed some light on the delicate dynamics of orbital collapse in the 3d shell. Our next experiment will be on laser-excited and laser-ionized manganese, a study which should solve the puzzle of the dramatic change in 3p-photoabsorption between chromium and manganese.

This work, done in collaboration with the Atomic and Plasma Radiation Division, also includes the development of laser-produced plasmas as intense, pulsed VUV sources. We have recently made the first photoelectric measurements of the VUV radiation emitted by seven target elements (Al, Cu, Sn, Sm, Yb, W, and Pb) of practical importance. Our

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next step is to intercompare our results with those of the PTB group who have calibrated a tungsten plasma source against the BESSY synchrotron. This NBS-PTB intercomparison will include the calibration of the PTB instrument on SURF II and the measurement of the NBS laser-produced source by the PTB spectrometer. The goals of this work are to develop the laser-produced plasma as a standard source and to develop criteria for the laser parameters to ensure maximum reproducibility and reliability.

Ultrasensitive Trace Analysis

The collaboration with the Mass Spectrometry Group in the Center for Analytical Chemistry has resulted in two major steps towards our goal of improving isotopic abundance sensitivities from two to five orders-of-magnitude utilizing the resonance ionization mass spectrometry (RIMS) technique.

The first step has been the installation and operation of a new RIMS system, including a new 12"-90° mass spectrometer of improved abundance sensitivity and a second pulsed dye laser for two-color resonance ionization. The second step has been the completion of the high resolution pulsed dye amplifier system necessary to exploit the narrowly spaced optical isotope shifts for isotope selection in the resonance ionization process.

The newly installed system has been tested at low resolution in studies of the doubly-excited 3pnd series in Mg. We have measured the energy positions and autoionizing widths of this level by using a two-color, two-step ionization process:

$$Mg(3s^2) + 2\hbar\omega_1 \rightarrow Mg^*(3snd)$$

$$Mg^*(3snd) + \hbar\omega_2 \rightarrow Mg^{**}(3pnd)$$

The $Mg^{**}(3pnd)$ autoionizing levels are of interest to those presently studying the dielectronic recombination rates of Mg^+ since a measurement of the autoionization rate gives a measurement of the time-reversed dielectronic recombination rate. Our experiments have again demonstrated the power of the RIMS technique to produce spectroscopic measurements on relatively inaccessible states. We expect to start experiments on isotope enhancement in the $^6Li/^7Li$ system in September 1985.

Atomic and Molecular Theory

Theoretical activity in the Far UV Physics Group is directed primarily at problems associated with atomic and molecular photoabsorption in the far ultraviolet spectral region and related topics such as excitation and ionization by charged particle impact. Recently, attention

has been given to multiphoton absorption processes, which afford an alternative means of accessing states in the same energy region.

During the past year we have been working, in collaboration with an experimental group at the Princeton Plasma Physics Laboratory, on some new approaches to generation of coherent radiation in the extreme ultraviolet (XUV) spectral region. The Princeton group has had notable success in obtaining amplified spontaneous emission of recombination radiation in hydrogen-like carbon, at a wavelength of 18 nm. Our current work is directed towards shorter wavelengths (less than 10 nm). The basic idea is to use high-order multiphoton absorption processes to produce population inversions in magnetically-confined ions, thus leading to amplified spontaneous emission (i.e., a soft x-ray laser). For example, there are transitions in krypton-like ions, in which a subvalence electron would be excited by absorption of many (10 or more) ultraviolet photons from a KrF excimer laser. Lasing action could then occur on transitions in which a valence electron drops into the subvalence hole. Our contribution to this work consists of theoretical spectroscopy of the various candidate atomic states, on most of which there exists no experimental information at present; and rudimentary theoretical analysis of very-high-order multiphoton processes. This latter subject is a focus of experimental attention worldwide, but as yet does not have a good theoretical underpinning.

Other work on multiphoton processes is primarily spectroscopy-oriented. We have published an analysis of an observation, by a group at CEN Saclay, of a resonance in eight-photon, double ionization of calcium. We are engaged in an analysis of two- and three-photon ionization of magnesium. This, and most of our other efforts on multiphoton problems, is done in a collaboration with the experimental program on ultrasensitive trace analysis described above.

We are continuing to work on problems of multiply-excited states of atoms and of Rydberg states in external fields. Work has begun on a comprehensive review of data on negative ion resonances, in collaboration with groups at the University of Aarhus (Denmark) and the Australian National University.

A workshop on Rydberg states in external fields and dielectronic recombination was held here in October 1984. Its proceedings have been published.

SURF Radiometric Intercomparison

A second intercomparison between the silicon photodiode, tungsten lamp, and synchrotron radiation irradiance scales was carried out in collaboration with the Radiometric Physics Division using a transfer

radiometer. The closure was 1-2%, a little poorer than previously obtained. It is now understood that very careful alignment of the radiometer with respect to the SURF electron orbit plane is critical to the measurement. The experiment will be repeated. This intercomparison was carried out in the visible region of the spectrum.

Another intercomparison was carried out this year between SURF II and the tungsten lamp irradiance scale at 297 nm using a uv spectroradiometer designed by H. Kostkowski for NOAA as the transfer instrument. The intercomparison was carried out by H. Kostkowski and J. Lean of the NOAA team with collaboration by the SURF staff and staff from Divisions 531 and 534 in the Center for Radiation Research. Both the closure and accuracy for this intercomparison was better than 2%. A publication is being prepared.

Spectrometer Calibrations

SURF II is used as a primary standard of spectral irradiance for the calibration of spectrometer and photometer systems in the spectral region 4-400 nm. These calibrations are primarily in support of programs of NASA and DoE, but important calibrations this year of two instruments for rocket-borne solar radiometry were also performed for NOAA. About 40 weeks in FY85 were utilized for 25 spectrometer calibrations including instruments for NOAA, GSFC, LASP, NRL, Utah State University, Johns Hopkins University, North Carolina State University, and Princeton University. The facility is solidly scheduled well into FY86. NASA support for this capability is expected to continue for the next five years.

Far UV Detector Calibrations

For about 15 years, NBS transfer standard photodiode detectors for the spectral range 5-320 nm have provided a radiometric base for users in such fields as aeronomy, astronomy, and plasma, solar, and solid state physics. During FY85, 16 calibrations were performed.

A new and improved far uv detector calibration system has been designed, constructed, and installed at SURF and is in the final phases of testing prior to performing outgoing calibrations. The system has demonstrated the capability of producing much more rapid calibrations with greatly improved spectral resolution and accuracy compared to the system previously used.

ELECTRON PHYSICS GROUP

The Electron Physics Group has ongoing research efforts in electron collision physics including electron-surface interactions, surface magnetism, electron interaction theory, electron polarization phenomena, electron-atom and electron-molecule collisions, and electron optics and instrumentation. The wide applicability of electron-based measurement technologies allows us to contribute to the solution of many diverse scientific and technological problems.

The past year has been an exceptionally good one for the Electron Physics Group. In last year's report, we described the strong interest in surface magnetism emerging from the scientific and technological community and the unusually good opportunities we saw to perform key experiments. We undertook three major new experimental efforts and refocused some of our ongoing projects. We felt that these new projects would position us well over the next 3-5 years in our effort to develop and demonstrate the basic measurement methods needed in this new field of research. We are finding that our predictions were correct, the only modifications being that the impact of some of our efforts may be greater than we had imagined and the time scale shorter than previously thought.

Inverse Photoemission

Our work on the scattering of spin-polarized electrons from surfaces continues with a high level of activity. As a consequence of our advancement of polarized electron source and detector technology, our experiments are continually breaking new ground. This is particularly true of our most recent work on surface magnetism. By using our polarized electron gun to observe the effects of the exchange interaction, we are able to sense the local net alignment of spins in the surface of a ferromagnet. The short mean free paths for elastically scattered electrons make this technique extremely surface-sensitive unlike neutron scattering.

Although in its infancy, inverse UV-photoemission has emerged as a very useful new method of gaining an understanding of the electronic structure of surfaces in general, and of ferromagnetic surfaces in particular. When used with the complementary method of photoemission spectroscopy, it is possible to gain a complete picture of the electronic structure.

The direct process, i.e., spin-polarized, angle-resolved, and energy-resolved photoemission, is normally observed using a high intensity synchrotron radiation source, a UV monochromator, an electron energy analyzer, and a spin polarization detector. We have demonstrated that it is possible to do the inverse experiment, where spin-polarized electrons

at a specific energy and angle of incidence are scattered from a target and the UV photons at a selected wavelength are detected. With a nickel (110) single crystal target, we demonstrated that only minority spin electrons are absorbed into unfilled d-bands and give rise to UV photons. This type of experiment allows one to observe the spin-polarized unfilled states near the Fermi level. By varying the angle of incidence we also measured the dispersion of these bands.

We continued our work in inverse photoemission by observing the effects caused when atoms and molecules are absorbed onto a ferromagnetic surface. We are interested in observing how the bonding of the absorbate to a surface affects the unfilled d-band of the substrate and how the magnetic character of the substrate changes. For atomic adsorption of oxygen on a Ni(110) surface we found a dramatic reduction in the Ni 3d minority holes, indicating that these states are strongly involved in the chemisorption bond. For the molecular chemisorption of CO on Ni(110) we saw a decrease in the Ni 3d minority states until one half of the surface Ni atoms have a CO molecule bonded to them. This is due to a non-local, chemisorption-induced reduction of the Ni magnetic moments. Transitions to the COπ^* band were also observed.

During the next year we will begin chemisorption experiments on the Ni(100) surface. This surface is easier to treat theoretically and we should be able to make detailed, direct comparisons with recent magnetic, surface band structure calculations.

Spin Polarized Photoemission

One of the three new efforts is a collaboration with Neville Smith of Bell Laboratories and Peter Johnson of Brookhaven National Laboratory. We will be using the technique of spin-polarized, angle-resolved photoemission to study surface magnetism. This has always been a powerful experimental technique in the past, but one in which the combination of low polarization detector efficiency and inadequate incident photon flux made investigations very difficult. This has been changed now by the advent of powerful new light sources and by our new, polarized electron detector. We will be using the undulator beam port on the VUV-ring at Brookhaven, which promises to offer the very high photon flux necessary for this experiment. The polarization detectors we will provide have the essential characteristics of high efficiency, small size, and low voltage operation. While operating at only 150 volts they possess the same efficiency as the most efficient Mott polarization detectors which operate at 120 KeV and which are not amenable to making angular measurements.

The apparatus is now under construction at Bell, Brookhaven, and NBS. We have completed the electron optical design necessary to couple our detector to the existing electron energy analyzer and have begun

construction of the polarization detectors. We hope, depending on scheduling for the storage ring, to begin our measurements at Brookhaven this winter.

New scientific opportunities are made possible by using the new, NBS polarization detectors coupled with the intense photon flux of the undulator beam line of the VUV-ring. These have attracted a great deal of interest from the scientific community interested in surface magnetism. As a result, a greatly expanded effort has been proposed involving three national laboratories, four universities, Bell Labs, DOE, and NSF. This effort will include studies of bulk materials as well as epitaxial ferromagnetic mono-, bi-, tri-layers, etc. Investigations will include ground-state magnetic properties, testing local-density-theory predictions, surface magnetic critical phenomena, spin-dependent photo-excitation, and energy and wave-vector resolved electron spectroscopy. There will also be a component of this research aimed at improving the insertion device to further enhance the available photon flux. We expect our existing experiment and instrumentation to serve as the prototype for a much larger program to begin in 1-2 years.

Polarized Electron Microscopy

Magnetic devices are getting smaller and smaller, and thin-film devices and media are becoming commonplace as the search for reliable, high density information storage techniques becomes more intense. Optical methods of studying magnetic phenomena are limited by diffraction to resolutions above a few microns and also do not possess the surface sensitivity that electron spectroscopies provide. There are, in addition, very fundamental questions to be answered concerning the magnetism of very small structures. For these reasons and others, we began our work on polarized electron microscopy.

As a result of our previous measurement of the spin polarization of secondary electrons emitted from ferromagnetic materials, we decided that it would be possible to measure the magnetization of surfaces with the spatial resolution of a scanning electron microscope (SEM), i.e., in the range 100-1000 A. This is because the secondary electrons emitted by the highly focused incident electron beam retain their spin orientation even after they are ejected from a magnetic surface. Hence, a measurement of their polarization reflects the vector magnetization of the material under the incident electron beam.

This year we completed the installation of three newly developed polarization detectors on the HB50A scanning electron microscope belonging to the NBS Center for Manufacturing Engineering (CME). In collaboration with G. Hembree of the Micro and Optical Metrology Group (CME), we have made preliminary observations of the magnetic domains of an iron-silicon

crystal using these detectors in both the pulse counting and analog mode. Our results have been very encouraging. The magnetic domains of an iron-silicon sample are clearly visible with a high level of contrast, and the magnetic imaging process is totally independent of the topographic image formation, which is accomplished simultaneously. Hence, the influence of physical structure on magnetic structure can be discerned and measured. Our measurements were made with a 100 A diameter electron beam. This promises to be the resolution limit of the technique after we eliminate present sources of sample vibration. By comparison, conventional SEM techniques give low contrast, do not measure vector magnetization, and convolute topographic and magnetic information. Widely used optical techniques are limited to 10,000 A resolution while a very great number of scientifically challenging and technologically significant questions arise below this resolution limit. A prime example is high density information storage in magnetic media.

We are working to build joint research arrangements with industry, other government laboratories, and universities. This will make optimum use of our unique capabilities in the near term and hasten the technology transfer of this new measurement technique. To date, we have received a large number of inquiries, many offers of test samples, and a wide exposure through meeting invitations and articles in the popular scientific press.

Electron Transport Theory

The polarized secondary electrons that play the key role in our magnetic imaging microscope possess a polarization which is a maximum for very low emitted energies and then falls to a constant value at higher secondary electron energies. The explanation for the shape of this curve has eluded theorists until this year when Dave Penn, in collaboration with Peter Apell (Guest Worker) and Steven Girvin (CCP), produced a theory which not only explained the experimental results but allowed the extraction of the ratio of the lifetimes of minority- to majority-spin electrons directly from the data. The physical basis of the theory involves the availability of holes for scattering of minority electrons at low energy, which further polarizes the emitted beam through attrition.

Electron-Atom Collisions

We are investigating electron-atom scattering in an experiment where all the parameters are determined so that we can make the step from measuring cross sections to the more fundamental determination of quantum phases and amplitudes. We have constructed a crossed beam, polarized-atom, polarized-electron scattering apparatus. Sodium atoms are polarized by optical pumping with a CW-dye laser. The electron beam comes from a GaAs polarized electron source. The use of a laser to optically orient

the sodium beam also facilitates measurement of polarization of the beam via laser fluorescence or Faraday rotation measurements. It is also possible to use this laser to optically pump the sodium to an excited, optically-oriented atomic state that could be studied by polarized electron scattering. In this past year we made first use of this capability to perform the first super-elastic, spin dependent measurements in electron-atom scattering.

Super-elastic scattering occurs when an electron collides with an atomic excited state, de-excites the atom during the collision, and then picks up the excitation energy. We used optical pumping to prepare an unpolarized beam of Na in the 3P state and studied the spin dependence of the super-elastic process as a function of scattering angle, incident energy, and the angle the peanut-shaped charge density of the Na atom made with the incident electron direction. Surprisingly, there was a strong dependence on incident electron spin direction. This spin asymmetry varies as a function of energy and both the scattering and atomic charge density orientation angles. We have found that this effect comes from a coupling between a spatial asymmetry in the super-elastic scattering cross section and the correlation of spin and angular momentum which occurs as a result of the optical pumping process. This new type of experiment promises to be a very stringent test of our ability to calculate low energy electron-atom interactions. Further, since it uniquely separates the spin-exchange part of the scattering problem from other effects, it should permit us to much better understand the role that exchange interaction models play in scattering calculations.

Scanning Tunneling Microscopy

In collaboration with CME, we have begun a small pilot program aimed at building a prototype scanning tunneling microscope to better understand its operation, advantages, disadvantages, and applicability to the solution of some outstanding problems in surface physics. Our first instrument is a third generation STM closely following the successful mechanical vibration isolation scheme used by IBM Zurich. We have successfully operated the instrument in air, scanning gold and pyrolytic graphite surfaces. We have observed regular structures from diffraction gratings and diamond-turned gold surfaces, and have seen steps of atomic dimensions on single crystal gold surfaces.

Our aim is to study the mechanisms of island formation and growth at the sub-monolayer level. We are assembling an ultra-high vacuum system with the necessary surface preparation and analysis systems, and expect to couple this with our STM this year. Our overall goal is to correlate surface microstructure with surface macroscopic properties. Areas of interest include surface lattice structure of metal and semiconductor

crystals, location of adsorbed gas molecules on surfaces, and thin film growth of metals on semiconductors.

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 533, Radiation Physics

C.W. Clark organized a workshop on Atomic Spectra and Collisions in External Fields held at NBS, Gaithersburg, MD, on October 22-23, 1984.

R.P. Madden coordinated the following workshops: "Machine Workshop on the 6 GeV Synchrotron Radiation Source" and "Synchrotron Radiation Steering Committee", NBS, Gaithersburg, MD, March 28-29, 1985.

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INVITED TALKS

Division 533, Radiation Physics

1. Celotta, R. J., "Polarized Electron Scattering; A New Tool for Surface Science," Colloquia, Braseleiro de Pesquisas Fisicas, Rio de Janeiro, Brazil, October 5, 1984.

2. Celotta, R. J., "The Application of Polarized Electron Spectroscopy to Surface Science," Colloquia, Instituto Politechnico National, Mexico City, Mexico, October 9, 1984.

3. Celotta, R. J., "Polarized Electrons: Recent Advances," Meeting of Latin American Surface Scientists, Oaxaca, Mexico, October 10, 1984.

4. Celotta, R. J., "Spin Polarized Electrons," Colloquium, Physics Department, Pennsylvania State University, University Park, PA, December 6, 1984.

5. Celotta, R. J., "Scanning Tunneling Microscopy," Solid State Physics Seminar, Physics Department, Pennsylvania State University, State College, PA, December 7, 1984.

6. Celotta, R. J., "Electron-Atom Collision Experiments Using Optically State Selected Beams," DEAP Annual Meeting, Norman, OK, May 29, 1985.

7. Celotta, R. J., "Scanning Tunneling Microscopy at NBS: A Progress Report," International Workshop on Scanning Tunneling Microscopy, IBM Europe Institute, Lech, Austria, July 2, 1985.

8. Celotta, R. J., "Recent Advances in Polarization Studies: Electron Microscopy and Exchange Scattering," Colloquium, Eidgenossische Technische Hochschule, Zurich, Switzerland, July 9, 1985.

9. Clark, C.W., "Chemical and Spectroscopic Consequences of the Lanthanide Contraction," Univ. of Illinois at Urbana-Champaign, Urbana. Illinois, February 5, 1985.

10. Clark, C.W., "Multiphoton Excitation of Autoionizing States," Argonne National Laboratory, Argonne, Illinois, February 7, 1985.

11. Clark, C.W., "Autodetaching and Core-Excited States of Negative Ions," Gordon Conference, Wolfeboro, New Hampshire, July 4, 1985.

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Division 533, Invited Talks (cont'd)

12. Clark, C.W., "Highly Excited Atoms in Electric and Magnetic Fields," Los Alamos, New Mexico, June 4, 1985.

13. Ederer, D.L., "The Synchrotron Radiation Program at NBS," Lawrence Berkeley Laboratory, Berkeley, California, March 13, 1985.

14. Ederer, D.L., "Photoionization of Laser-Excited Atoms by Synchrotron Radiation," Lawrence Livermore National Laboratory, Livermore, California, March 14, 1985.

15. Ederer, D.L., "A Review of the Synchrotron Radiation Program at NBS-SURF," Photon Factory, Tsukuba, Japan, March 20, 1985.

16. Ederer, D.L., "Synchrotron Radiation as an Atomic Physics Probe," and "The Synchrotron Radiation Program at NBS-SURF," Taipei, Taiwan, March 20-25, 1985.

17. Ederer, D.L., "Phun With Photoionization," Tsing Hua University, Taiwan, March 26, 1985.

18. Ederer, D.L., "Hybrid Laser-Synchrotron Radiation Experiments in Metal Vapors," University of Southern California, Los Angeles, California, March 28, 1985.

19. Ederer, D.L., "Photoionization of Excited Atoms by Synchrotron Radiation: Sodium and Barium," Gordon Conference, Wolfeboro, New Hampshire, July 3, 1985.

20. Feigerle, Charles S., "Spin Polarized Inverse Photoemission Studies of O_2 Chemisorbed on Ni(110)," National Meeting of the Mexican Vacuum Society, Taluca, Mexico, October 10, 1984.

21. Feigerle, Charles S., "Spin Polarized Inverse Photoemission Measurements of the Effect of Chemisorption on Ni: A Band Specific Technique," Joint Institute for Laboratory Astrophysics, Boulder, CO, October 15, 1984.

22. Feigerle, Charles S., "The Electronic Structure of Transition Metals in the Gas and Solid State, UCLA Department of Chemistry, Los Angeles, CA, January 16, 1985.

Division 533, Invited Talks (cont'd)

23. Feigerle, Charles S., "The Electronic Structure of Transition Metals in the Gas and Solid State, University of Tennesse, Dept. of Chemistry, Knoxville, TN, Februrary 18, 1985.

24. Feigerle, Charles S., "The Electronic Structure of Transition Metals in the Gas and Solid State, Oak Ridge National Laboratory, Oak Ridge, TN, February 19, 1985.

25. Hughey, L.R., "Vacuum Compatibility Criteria Used at SURF-II, the NBS Electron Storage Ring," Fusion Technology Division of the American Vacuum Society and NBS, Holiday Inn, Gaithersburg, MD, May 7-9, 1985.

26. Klebanoff, L. K., "Photoelectron Spectroscopy Studies of Cr(001) Surface Magnetism," International Conference on Magnetism, San Francisco, CA, August 27, 1985.

27. Kelley, M. H., "Electron-Atom Collision Studies Using Optically State Selected Beams," Symposium on Polarization and Correlation in Electron-Atom Collisions, Pasadena, CA, August 2, 1985.

28. Lucatorto, T.B., and McIlrath T.L., "Techniques for Studying Autoionization in Isoelectronic and Isonuclear Sequences," Workshop on Autoionization in Atoms and Small Molecules, Argonne National Laboratory, Argonne, IL, May 2, 1985.

29. Lucatorto, T.B., "Techniques for Creating and Observing Atomic Excited States and Ions: Applications to Atomic Structure," Physics Department, University of California at Berkeley, May 14, 1985.

30. Lucatorto, T.B., "Techniques for Creating and Observing Atomic Excited States and Ions: Applications to Atomic Structure," Applied Physics Seminar, Stanford University, Stanford, California, May 15, 1985.

31. Madden, R.P., "SURF II Facility Up-Grade Plan," Synchrotron Radiation Center User Meeting, Stoughton, Wisconsin, October 22, 1984.

32. Madden, R.P., "The SURF-II Facility Up-Grade Plan at NBS," NRC Committee on Atomic and Molecular Sciences (CAMS) Workshop on VUV and X-Ray Sources, National Academy of Sciences, Washington, DC, November 9, 1984.

Division 533, Invited Talks (cont'd)

33. Madden, R.P., "Experimental Program at the NBS Synchrotron Ultraviolet Radiation Facility," Denton, Texas, November 12, 1984.

34. McClelland, J. J., "Observations of Spin Dependence in Superelastic Scattering of Polarized Electrons from Na(3P)," XIV ICPEAC, Palo Alto, CA, July 30, 1985.

35. Ott, W. R., "Dosimetry Research and Measurement Activities at NBS," Seminar for Metrology Technicians at Butler County Community College, Butler, Pennsylvania, March 22, 1985.

36. Parr, A.C., "Molecular Photoionization Studies Using Synchrotron Radiation," Lehigh University, Bethlehem, Pennsylvania, March 29, 1985.

37. Parr, A.C., "Molecular Photoionization Studies Using Synchrotron Radiation", Los Alamos National Laboratory, Los Alamos, New Mexico, May 2, 1985.

38. Penn, D. R., "Spin Polarization of Secondary Electrons," City College of New York, NY, March 13, 1985.

39. Pierce, D. T., "Chemisorption Induced Changes in Surface Magnetism and Electronic Structure of Ni(110)," AT&T Bell Laboratories, March 8, 1985.

40. Pierce, D. T., "Spin Polarized Inverse Photoemission Studies of Surface Magnetism and Electronic Structure," International Conference on Magnetism, San Francisco, CA, August 1985.

41. Rakowsky, G., "Coherent Synchrotron Relaxation Oscillation in an Electron Storage Ring," 1985 Particle Accelerator Conference, Vancouver, British Columbia, Canada, May 15, 1985.

42. Alfred Seiler, "Connection Between Surface Magnetism and Electronic Structure of Oxygen on Ni(110), Magnetism and Magnetic Materials Conference, November 29, 1984.

43. Unguris, J., "High Resolution Polarized Electron Microscopy," The 11th Colloquium on Magnetic Films and Surfaces, Asilomar, CA, September 2, 1985.

PUBLICATIONS

Division 533, Radiation Physics

Bizau, J.M., Wuilleumier, W., Gerard, P., Dhez, P., Carré, B., Spiess, G., Ederer, D.L., Picqué, J.L., LeGouët, J.L. Keller, J.C., and Koch, P., Observation of Ionization of Laser Excited Atoms by Synchrotron Radiation, Proc. IAU Colloquium 86; EUV and X-ray Spectroscopy, Astrophysical and Laboratory Plasmas; ed. G. Doschek (August 1984).

Butler, J.J., Holland, D.M.P., Parr, A.C., Stockbauer, R.L., and Buff, R., Automation of the NBS Threshold Photoelectron-Photoion Coincidence Mass Spectrometer, J. Phys E Sci. Instr. 18, 286 (1985).

Carré, B, Bizau, J.M., Cubaynes, D., Dhez, P., Ederer, D.L., Gerard, P., Keller, J.C., Koch, P.M., LeGouët, J.L. Picqué, J.L., Roussell, F., Spiess, G., and Wuilleumier, F., Collisional Ionization in a Resonantly Excited Atomic Vapor, Proc. of Atomic and Molecular Collisions in a Laser Field, Jour. de Physique, Colloque C1, Supp. No. 1, 46, 163, January 1985.

Carré, B., Bizau, J.M., Dhez, P., Ederer, D.L., Gérard, P., Keller, J.C., Lock, P.M., LeGouët, J.L. Picqué, J.L., Spiess, G., and Wuilleumier, F., Electron Spectrometry Study of Associative and Penning Ionization in Laser Excited Sodium Vapors, Optics Comm. 52, 29 (1984).

Celotta, R.J., and Levine, J., Editors-in-Chief; Munday, J.A., Rothman, S.J., Fluss, M.H., and Smedskjaer, C., Editors, Methods of Experimental Physics, 21, Solid State Physics: Nuclear Methods, Academic Press, (1983).

Celotta, R.J., and Levine, J., Editors-in-Chief; Park, R.L., and Lagally, M.G., Editors, Methods of Experimental Physics, 22, Solid State Physics: Surfaces, Academic Press (1985).

Clark, C.W., Korevaar, E., and Littman, M.G., Quasi-Penning Resonances of a Rydberg Electron in Crossed Electric and Magnetic Fields, Phys. Rev. Lett. 54, 329 (1985).

Clark, C.W., Fassett, J.D., Lucatorto, T.B., Moore, L.J., and Smith, W.W., Observation of Autoionizing States of Beryllium by Resonance Ionization Mass Spectrometry, J. Opt. Soc. Am. B. 2, 891 (1985)

Clark, C.W., Electron-Atom Scattering in External Fields, Atomic Excitation and Recombination in External Fields, ed. M.H. Nayfeh and C.W. Clark (Harwood Academic Publishers, N.Y. 1985).

Division 533, Publications (cont'd.)

Cromer, C.L., Bridges, J.M., Lucatorto, T.B., and Roberts, J.R., A High-Resolution VUV Spectrometer with Electronic Parallel Spectral Detector, AIP Conf. Proc. 119 "Laser Techniques in the XUV," Boulder, CO, 180, (1984).

Cromer, C.L. Bridges, R.M., Roberts. J.R., and Lucatorto, T.B., A High-Resolution VUV Spectrometer with Multichannel Detector for Absorption Studies of Transient Species, Appl. Opt. 24, 20 (1984).

Cromer, C.L. and Clark, C.W., Resonant Structure in Multiphoton Ionization of Calcium, J. Phys. B 18, L497 (1985).

Dehmer, J.L., Southworth, S.H., and Parr, A.C., Triply Differential Photoelectron Studies of Resonances in Molecular Photoionization, NIM B 10 247 (1985).

Dehmer, J.L., Parr, A.C., Southworth, S.H., and Holland, D.M.P., Angle-Resolved Photoelectron Study of the Valence Levels of BF_3 in the Range 17 $\leq h\nu \leq$ 28 eV, Phys. Rev. 30, 1783 (1984).

Feigerle, C.S., Pierce, D.T., Seiler, A., and Celotta, R.J., An Intense Source of Monochromatic Electrons: Photoemission from GaAs, Appl. Phys. Lett. 44, 866 (1984).

Feigerle, C.S., Seiler, A., Peña, J.L., Celotta, R.J., and Pierce, D.T., Chemisorbed Oxygen on Ni(110) Studied by Spin Polarized Inverse Photoemission, J. Vac. Sci. Technol. A, 3(3), 1487 (1985).

Feigerle, C.S., Pierce, D.T., Seiler, A., and Celotta, R.J., High Current, Monochromatic Electron Source for Polarized Scattering, Int. Conf. on Phys. of Electron and Atomic Collisions (ICPEAC), San Francisco, CA (1985).

Greene, C.H. and Clark, C.W., Adiabatic Hyperspherical Treatment of Lithium $^{2p^0}$ States, Phys. Rev. A. 30 2161 (1984).

Hill, W.T., Non-Resonant Laser-Driven Ionization of Condensing Vapors: A Mechanism Based on Cluster Fragmentation, Optics Comm. 54, 283 (1985).

Kelley, M.H., Celotta, R.J., and Pierce, D.T., Electron-Atom Collision Studies Using Optically State Selected Beams, Proceedings of Department of Energy Workshop on Atomic Physics (1984).

Klose, J.Z., Bridges, J.M., and Ott, W.R., Monochromatic Source of Lyman Alpha Radiation, Appl. Opt. 24, 2039 (1985).

Division 533, Publications (cont'd.)

Leroi, G.E., Dehmer, J.L., Parr, A.C., and Poliakoff, E.D., Polarization of Fluorescence: A Probe of Molecular Autoionization, Proc. of Israeli Phys. Soc. 6, 207 (1983).

Madden, R.P., Ederer, D.L., and Parr, A.C., Experimental Program at NBS Synchrotron Ultraviolet Radiation Facility, Proceedings of the Conference on the Application of Accelerators in Research and Industry, Nucl. Inst. and Meth. B10/11, 289-292 (1985).

McClelland, J.J. and Fink, M., Electron Correlation and Binding Effects in Measured Electron Scattering Cross Sections of CO_2, Phys. Rev. Lett. 54, 2218 (1985).

McClelland, J.J. and Fink, M., Correlation Effects in Neon Studied by Elastic and Inelastic High-Energy Electron Scattering, Phys. Rev. A 31, 1328 (1985).

McClelland, J.J. and Kelley, M.H., Detailed Look at Aspects of Optical Pumping in Sodium, Phys. Rev. A, 31(6), 3704 (1985).

McClelland, J.J., Kelley, M.H., and Celotta, R.J., Spin Dependence in Superelastic Scattering from Na(3P), Phys. Rev. Lett. 55, 688 (1985).

McClelland, J.J., and Kelley, M.H., Diagnosis of Spin Polarization in an Optically Pumped Sodium Beam, Proceedings, Int. Conf. on Physics of Electron and Atomic Collisions (ICPEAC), San Francisco, CA (1985).

McClelland, J.J., Kelley, M.H., and Celotta, R.J., Electron-Atom Collision Studies Using Optically State Selected Beams: Superelastic Scattering, Proceedings, Symposium of Polarization and Correlation in Electron-Atom Collisions (Abstract), Pasadena, CA (1985).

McClelland, J.J., Kelley, M.H., and Celotta, R.J., Observations of Spin Dependence in Superelastic Scattering of Polarized Electrons from Na(3p), International Conference on Physics of Electron and Atomic Collisions (ICPEAC Invited Papers), San Francisco, CA (1985).

Nayfeh, M.H. and Clark, C.W., Introduction, Atomic Excitation and Recombination in External Fields, ed. M.H. Nayfeh and C.W. Clark (Harwood Academic Publishers, N.Y., 1985).

Penn, D.R., Wave-Number-Dependent Dielectric Function of a Semiconductor, Citation Classic in Current Contents/Physical, Chemical & Earth Sciences, 25(6), 20 (1985).

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Division 533, Publications (cont'd.)

Penn, D.R., Apell, S.P., and Girvin, G.M., Theory of Spin-Polarized Secondary Electrons in Transition Metals, Phys. Rev. Lett. 55, 518 (1985).

Pierce, D.T., and Celotta, R.J., Applications of Polarized Electron Sources Utilizing Optical Orientation in Solids, in Optical Orientation, ed. F. Meier and P. Zakharchenya, part of the North Holland Series "Modern Problems in Solid State Physics," Chapter 6, pp. 259 (1984).

Poliakoff, E.D., Dehmer J.L., Parr, A.C, and Leroi, G.E., "Fluorescence Excitation Studies of Molecular Photoionization in External Electric Fields," Proc. of Israeli Phys. Soc. 6, 1207 (1983).

Saloman, E.B. Cooper, J.W., and Kelleher, D.E., Electric Field-Induced Interferences in Autoionizing Resonances, Phys. Rev. Lett., 55, 193 (1985).

Schaefer, A.R., Saunders, R.D., and Hughey, L.R., Intercomparison Between Independent Irradiance Scales Based on Silicon Photodiode Physics, Gold Point Blackbody Radiation, and Synchrotron Radiation, SPIE 499 Opt. Rad. Meas. (1984).

Seiler, A., Feigerle, C.S., Peña, J.L., Celotta, R.J., and Pierce, D.T., Connection Between Surface Magnetism and Electronic Structure of Oxygen on Ni(110), J. Appl. Phys. 57(1), 3638 (1985).

Unguris, J., Hembree, G.G., Pierce, D.T., and Celotta, R.J., Scanning Electron Microscopy with Secondary Electron Spin Polarization Analysis: A New Probe of Magnetic Microstructure, Book of Abstracts, 45th Ann. Conf. on Physical Electronics, University of Wisconsin, Milwaukee, WI, pp. E-8 (1985).

Unguris, J., Pierce, D.T., and Celotta, R.J., Spin-Polarized Electron Scattering Studies of the Ferromagnetic Glass, $Fe_{81.5}B_{14.5}Si_4$, Phys. Rev. B 29(3), 1381 (1984).

PUBLICATIONS IN PREPARATION

Division 533, Radiation Physics

Bizau, J.M., Wuilleumier, F., Ederer, D.L., Keller, J.C., LeGouët, J.L., Picqué, J.L., Carré, B., and Koch, P., Oscillator Strength Measurements of Even Parity Autoionization Resonances in Neutral Sodium from Combined Synchrotron Radiation Laser Excitation (submitted to Phys. Rev. Lett).

Feigerle, C.S., Seiler, A., Peña, J.L., Celotta, R.J., and Pierce, D.T., CO Chemisorption on Ni(110): Effect on Ni Surface Magnetism and Formation of $C\sigma\pi^*$ Band, Phys. Rev. (submitted).

Hill, W.T., Quenching of Resonant Laser-Driven Ionization by High Buffer Gas Pressures (submitted to J. Phys. B).

Klebanoff, L., Robey, W.W., Liu, G., Shirley, D.A., Photoelectron Spectroscopy Studies of Cr(001) Near-Surface and Surface Magnetism, Proceedings, Journal of Magnetism and Magnetic Materials (to be published).

Krause, M.O., Svensson, W.A., Carlson, T.Z., Leroi, G., Ederer, D.E., Holland, D.M.P., and Parr, A.C., Photoeffect in the 4d Subshell of Atomic Silver Between 14 and 140 eV (submitted to J. Phys. B).

McIlrath, T.J. and Lucatorto, T.B., Techniques for Studying Autoionization in Isoelectronic and Isonuclear Sequences (in progress).

Moore, L.J., Fassett, J.D., Travis, J.C., Lucatorto, T.B., and Clark, C.W., Resonance Ionization Mass Spectrometry of Carbon, J. Opt. Soc. Am. B 2, Sec. 9 (to be published, September 1985).

Parr, A.C., Synchrotron Radiation: Applications to Chemistry, book chapter in Analytical Techniques, to be published by Texas A & M University Press.

Penn, D.R., Apell, P.S., and S.M. Girvin, Spin Polarized Secondary Electrons, Theory, Journal of Magnetism and Magnetic Materials, (submitted).

Pierce, D.T., Seiler, A. Feigerle, C.S., Peña, J.L., and Celotta, R.J., Spin Polarized Inverse Photoemission Studies of Surface Magnetism and Electronic Structure, Proceedings, Journal of Magnetism and Magnetic Materials (submitted).

Division 533, Publications in Preparation (cont'd.)

Rakowsky, G., Coherent Synchrotron Relaxation Oscillation in an Electron Storage Ring, to be published in IEEE Trans. Nucl. Sci.

Saloman, E.B., Cooper, J.W., and Mehlman, G, Photoabsorption of Barium from 237.9 nm to 120 nm, Phys. Rev. (1985) (in press).

Saloman, E.B. and Hubbell, J.H., Critical Analysis of Soft X-Ray Cross Section Data (Proc. of Third Int. Symp. on Radiation Physics, Ferrara, Italy, 1985).

Seiler, A, Feigerle, C.S., Pena, J.L., Celotta, R.J., and D.T. Pierce, Chemisorption Induced Changes in Surface Magnetism and Electronic Structure: Oxygen on Ni(110), Phys. Rev. Lett. (in press).

Seiler, A., Feigerle, C.S., Celotta, R.J., Pierce, D.T., and Smith, N.V., Spin Dependence of Unoccupied States on Ni(110), Phys. Rev. B (submitted).

Snyder, J.J., Lucatorto, T.B., Debenham, P.H., and Geltman, S., Ultra-sensitive Laser Isotope Analysis in an Ion Storage Ring (submitted to Opt. Soc. of Am. B).

Taylor, K.T., Clark, C.W., and Fon, W.C, Electron Scattering by Neon in Resonance Regions, J. Phys. B 18 (1985) (in press).

Unguris, J., Hembree, G.G., Celotta, R.J., Pierce, D.T., High Resolution Magnetic Microstructure Imaging Using Secondary Electron Spin Polarization Analysis in a Scanning Electron Microscope, J. of Microscopy (in press).

Unguris, J., Hembree, G.G., Celotta, R.J., and D.T. Pierce, Investigations of Magnetic Microstructures Using Scanning Electron Microscopy with Spin Polarization Analysis, Proceedings, International Conference on Magnetism (1985), Journal of Magnetism and Magnetic Materials (submitted).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION

Division 533, Radiation Physics

Robert J. Celotta

Member, General Committee, International Conference on the Physics of Electron and Atomic Collisions.

Member, NBS Computer Network Committee.

Co-chair, NBS Atomic Physics Colloquium Committee.

Member, DEAP Local Organizing Committee.

Michael H. Kelley

NBS Advisory Group for Graphics.

David L. Ederer

Member, Optics News Editorial Committee.

Member, Education Committee, Optical Society of America.

Thomas B. Lucatorto

Advisory Panel, 1986 Conference on Laser Techniques in the Extreme Ultraviolet.

Co-chairman, 1989 ICPEAC Local Organizing Committee.

Robert P. Madden

Member SRC Users' Advisory Committee for the Stoughton Storage Rings (Tantalus and Aladdin) of the University of Wisconsin).

Member, Advisory Editorial Board of Optics Communication.

Chairman, International Committee for the International Conference on VUV Radiation Physics.

Member, Council of Scientific Society Presidents (CSSP) (terminated 12/31/84).

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Division 533, Technical and Professional Committee Paricipation and Leadership (cont'd)

Robert P. Madden (cont'd)

Member, CSSP Executive Committee, 1984 (terminated 12/31/84).

Member, Middle Atmospheric Program International Working Group on Solar Spectral Irradiance Measurements.

Coordinator, Council of U.S. Synchrotron Radiation Laboratory Directors.

Member, International Committee of the International Conference on X-Ray and VUV Synchrotron Radiation Instruments.

Member, Optical Society of America Objectives and Policy Committee.

Member, Physics Today Advisory Committee of the American Institute of Physics (terminated 12/31/84).

Member, Synchrotron Radiation Facility Working Group (Department of Energy).

Member, Interagency Group for Intense Light Sources.

Member, U.S. Organizational Committee for the October 1985 Workshop on the Construction and Commissioning of Dedicated Synchrotron Radiation Facilities.

Member, Synchrotron Radiation Source and Research Development Committee.

Thomas J. McIlrath

Chairman, 1984 Meggers Award Committee, Optical Society of America.

Member, National Research Council Committee of Line Spectra of the Elements--Atomic Spectroscopy.

Vice Chairman, 1985 Gordon Conference on Atomic Physics.

Advisory Panel, 1986 Conference on Laser Techniques in the Extreme Ultraviolet.

Advisory Editor, Laser Focus Magazine.

Division 533, Technical and Professional Committee Participation and Leadership (cont'd)

William R. Ott

Member, International Working Group for Middle Atmosphere Program on Solar Spectral Irradiance Measurements, 1981-1985.

Treasurer, Pro-tem Committee (now forming), International Radiation Physics Society.

Member, International Advisory Board for 3rd International Symposium on Radiation Physics, Ferrara, Italy, September, 1985.

Member, SBUV/METSAT Calibrations Advisory Committee, NASA Goddard Space Flight Center, 1981-1985.

Member, NBS-CRR Calibrations Advisory Committee

Daniel T. Pierce

Executive Committee, Surface Science Division of the American Vacuum Society

Chairman, AVS Morton M. Traum Surface Science Student Award Committee

Program Committee, 11th International Colloquium on Magnetic Films and Surfaces, Asilomar, CA

International Organizing Committee, International Colloquium on Magnetic Films and Surfaces

Vice Chairman, Gordon Conference on Electron Spectroscopy

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MAJOR CONSULTING AND ADVISORY SERVICES

Division 533, Radiation Physics

1. R. J. Celotta and D. T. Pierce consulted on the production and detection of polarized electrons with researchers from Brookhaven, AT&T Bell Labs, University of Texas, Princeton, Kimball Physics Corporation, Rice University, University of Oklahoma, City College of New York, MIT, University of Adelaide (Australia), University of Mainz (West Germany), and the Naval Research Laboratory.

2. C. W. Clark advises a group at Princeton Plasma Physics Laboratory on atomic physics problems associated with x-ray laser development.

3. D. T. Pierce consulted with R. O'Handly, MIT, on utilizing a spin detector with a cylindrical mirror energy analyzer for spin polarized Auger measurements.

4. D. T. Pierce consulted with G. J. Lapeyer, Montana State University, on construction of a spin polarized electron source.

JOURNAL EDITORSHIPS

Division 533, Radiation Physics

R.J. Celotta, Series Editor, Methods of Experimental Physics.

R.J. Celotta, Editorial Board, Review of Scientific Instruments.

D.T. Pierce, Editorial Board, Review of Scientific Instruments.

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TRIPS SPONSORED BY OTHERS

Division 533, Radiation Physics

Robert J. Celotta gave a talk at the Colloquia, Instituto Politechnico National, Mexico City, Mexico, October 9, 1984.

Robert J. Celotta gave an invited talk at the Meeting of Latin American Surface Scientists, Oaxaca, Mexico, October 10, 1984.

Robert J. Celotta gave a colloquium to the Physics Department, Pennsylvania State University, University Park, PA, December 6, 1984.

Robert J. Celotta presented a talk to the Solid State Physics Seminar, Physics Department, Pennsylvania State University, State College, PA, December 7, 1984.

Robert J. Celotta presented an invited talk to the International Workshop on Scanning Tunneling Microscopy, IBM Europe Institute, Lech, Austria, July 2, 1985.

Robert J. Celotta gave a colloquium, Eidgenossische Technische Hochschule, Zurich, Switzerland, July 9, 1985.

C.W. Clark presented an invited seminar and visited research groups at Argonne National Laboratory and the University of Illinois, February 3-9, 1985.

C.W. Clark consulted on X-ray Laser Development at Princeton Plasma Physics Laboratory, Princeton, New Jersey, January 1-2, 1985.

C.W. Clark consulted on X-ray Laser Development at Princeton Plasma Physics Laboratory, Princeton, New Jersey, June 12, 1985.

C.W. Clark consulted on X-ray Laser Development at Princeton Plasma Physics Laboratory, Princeton, New Jersey, April 1, 1985.

C.W. Clark visited and presented a talk at Los Alamos National Laboratory, Los Alamos, New Mexico, June 3-5, 1985.

C.W. Clark attended the Gordon Conference as an invited speaker, Wolfeboro, New Hampshire, June 30-July 5, 1985.

C.W. Clark consulted on X-ray Laser Development at Princeton Plasma Physics Laboratory, Princeton, New Jersey, September 19, 1985.

Division 533, Trips Sponsored by Others (cont'd)

D.L. Ederer attended the Gordon Conference as an invited speaker, Wolfeboro, New Hampshire, June 30-July 5, 1985.

D.L. Ederer attended a workshop on the use of synchrotron radiation for atomic and molecular physics and presented two lectures in Taipei, Taiwan; he visited the Photon Factory in Tokyo, Japan and presented a lecture at the user meeting, March 13-31, 1985.

Charles S. Feigerle presented an invited talk to the Joint Institute for Laboratory Astrophysics, Boulder, CO, October 12, 1985.

Charles S. Feigerle presented an invited talk to the Department of Chemistry, UCLA, Los Angeles, CA, January 8, 1985.

C.S. Feigerle presented invited talks at the University of Tennessee, Knoxville, Tennessee and Oak Ridge National Laboratory, Oak Ridge, Tennessee, February 17-19, 1985.

Michael H. Kelley gave a talk to the International Symposium on Correlation and Polarization in Electron-Atom Collisions, Pasadena, CA, August 1, 1985.

Leonard E. Klebanoff presented a talk to the 45th Conference on Physical Electronics, Milwaukee, WI, June 17, 1985.

T.B. Lucatorto consulted and presented an invited talk at the University of California, Berkeley, California, and Lawrence Livermore Laboratory, Livermore, California, May 13-16, 1985.

T.B. Lucatorto attended a workshop on Autoionization of Atoms and Small Molecules at Argonne National Laboratory, Chicago, Illinois, May 2-3, 1985.

R.P. Madden attended the National Laser User's Facility Steering Committee at the University of Rochester, Rochester, New York, March 3-4, 1985.

R.P. Madden attended the Social Objectives and Policy (SOAP) Committee meeting, the meeting on Optical Computing, and the meeting on Picosecond Optoelectronics, Lake Tahoe, Nevada, March 12-27, 1985.

A.C. Parr consulted and gave an invited talk at Los Alamos National Laboratory, Albuquerque, New Mexico, May 1-4, 1985

Division 533, Trips Sponsored by Others (cont'd)

David R. Penn presented a talk at the City College of New York, NY, March 13, 1985.

Daniel T. Pierce presented a talk at AT&T Bell Laboratories, Murray Hill, NJ, March 8, 1985.

John Unguris presented a talk to the 45th Annual Conference on Physical Electronics, Milwaukee, WI, June 19, 1985.

John Unguris presented a talk to the International Conference on Magnetism, San Francisco, CA, August 30, 1985.

B. Sonntag attended the DEAP conference as an invited speaker, Norman, Oklahoma, May 28-31, 1985.

B. Sonntag attended a workshop on Autoionization of Atoms and Small Molecules at Argonne National Laboratory, Chicago, Illinois, May 1, 1985.

B. Sonntag attended the Gordon Conference as an invited speaker, Wolfeboro, New Hampshire, June 30-July 5, 1985.

CALIBRATION SERVICES PERFORMED

Division 533, Radiation Physics

Type of Service	Customer Type*	SP 250 Item No.	Number of Calibrations or Tests	Income
Far UV radiometric transfer standard detectors (photodiode calibrations)	1,4-8	N.A.	16	$ 23K
Totals			16	$ 23K

*Column 2: 1, calibration labs; 2, hospitals; 3, nuclear energy establishments; 4, industry; 5, US government labs; 6, DoD labs; 7, universities; 8, foreign governments.

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SPONSORED SEMINARS AND COLLOQUIA

Division 533, Radiation Physics

Best, Philip E., Physics Department, University of Connecticut, Storrs, Connecticut, "Towards Improved Temporal Resolution in Electron Spectrometry," October 19, 1984.

Hotop, Hartmut, Universität Kaiserslautern, West Germany, "Photoionization of Laser Excited Rare Gas Atoms," November 13, 1984.

de Vries, Mattanjah, University of Maryland, College Park, Maryland, "Shedding Light on Atom-Molecule Collisions," November 15, 1984.

Cavagnero, Michael, University of Chicago, Chicago, Illinois, "Correlations of Atomic Valence Electrons," January 8, 1985.

Baratoff, Alexis, IBM Zurich, Switzerland, "The Present Status of Scanning Tunneling Microscopy," February 6, 1985.

Helman, J. S., Centro Brazileiro de Pasquisas Fisicos, Rio de Janeiro, Brazil, "Spin Relaxation of Iron in Hemoproteins," March 21, 1985.

Clauberg, Rolf, KFA Julich, W. Germany, "Determination of Finite Temperature Short Range Magnetic Order in Itinerant Ferromagnets by Spin Polarized Photoemission," April 1, 1985.

Leubner, Christoph, Institute for Theoretical Physics, University of Innsbruck, Austria, "Accurate Synchrotron Spectra for Planar Strong Field Wigglers With Arbitrary Field Variation," April 1, 1985.

Gradmann, U., Technical University of Clausthal, W. Germany, "Magnetism at Surfaces and Interfaces," April 2, 1985.

Nenner, Irene, Commissariat a L'Energie Atomique, Centre d'Etudes Nucleaire de Saclay, France, "Molecular Photoionization Using Synchrotron Radiation at LURE," April 29, 1985.

Hansma, Paul, University of California at Santa Barbara, Santa Barbara, California, June 13, 1985.

Azria, Richard, C.N.R.S. Laboratoire de Collisions Atomiques et Moleculaire, Orsay, France, "Negative Ion Formation in Polar and Highly Polar Molecules," June 17, 1985.

Sponsored Seminars and Colloquia (cont'd)

Christensen-Dalsgaard, Birte, H.C. Oersted Institut, University of Copenhagen, Copenhagen, Denmark, "Correlation Effects in Negative Alkali Ions," July 12, 1985.

Buckman, Stephen J., Research School of Physical Sciences, Australian National University, Canberra, Australia, "Recent Experiments in Electron-Atom Scattering," July 22, 1985.

Riehle, F., Physikalisch-Technische Bundesanstalt, Institut Berlin, "Radiometric Measurements at BESSY," July 24, 1985

Sawatzky, George, University of Groningen, The Netherlands, "The Electronic Structure, Bandgap, and Spectroscopic Properties of Transition Metal Compounds," August 20, 1985.

Dhez, Pierre, LURE, Université Paris-Sud, Orsay, France, "Progress in XUV Multilayer Development: Survey of the Collective French Effort," August 29, 1985.

Guntherodt, G., Universitat zu Köln, W. Germany, "Spin-Resolved Photoemission and Electron Scattering from Itinerant Ferromagnets," September 11, 1985.

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TECHNICAL ACTIVITIES

Division 534, Radiometric Physics

Task No. 15241: Advanced Optical Radiation Measurements
Task No. 15242: Maintenance and Dissemination of Optical Radiation Measurements
Task No. 26107: Quantum Radiometry

INTRODUCTION

The Radiometric Physics Division of the Center for Radiation Research is the primary unit within NBS for carrying out the traditional Bureau role of promoting accurate, meaningful, and compatible optical radiation measurements in the near-uv, visible, and near-ir spectral regions. The Division is organizationally subdivided into four Groups:

Spectroradiometry and Optical Pyrometry. Conducts applied research to develop new instrumentation and to improve and extend radiometric and pyrometric standards and calibration procedures.

Spectrophotometry. Provides high-accuracy spectrophotometric measurements, standards, and measurement assurance procedures. Develops new methods for the radiometric characterization of optical media and components.

Photodetector Physics and Metrology. Develops new, detector-based radiometric standards and methods to complement and extend traditional, source-based radiometry.

Radiometric Measurement Services. Provides, improves, and extends radiometric and photometric calibrations, implements measurement assurance programs, and participates in radiometric intercomparisons.

As will be seen from the following reports of the four Group Leaders, each Group produced important results during FY 1985.

Division 534 has been responsive to the continuing emphasis by NBS management on improved delivery of radiometric measurement services. Calibration billings in pyrometry, radiometry, photometry, and spectrophotometry increased by 25% during FY 1985, turnaround times for detector responsivity and other calibrations were reduced significantly, and new measurement services for spectrophotometry have been established. Research to extend the wavelength range of spectral irradiance calibrations to 2400nm has been completed. Three new measurement facilities (the photoelectric pyrometer, the detector response comparator, and the reference spectrofluorimeter) are now ready for routine calibrations of standards.

The Division plans further expansions of its metrology programs, and has made the following changes in group responsibilities and personnel assignments in order to facilitate this goal:

(a) The Spectroradiometry and Optical Pyrometry Group will concentrate its efforts on providing the scientific and technological basis for measurement services in radiometry. We are currently seeking a new leader for this Group with a background in optics, experience in radiometry, commitment to metrology, and leadership qualities.

(b) The responsibilities of the Photodetector Physics and Metrology (formerly Quantum Radiometry) Group have been broadened to include the development and implementation of detector applications in addition to performing basic research on the physics of detectors. Belzer, Thomas, and Zalewski have been assigned to this Group.

(c) The Radiometric Measurement Services (formerly Calibrations) Group has assumed responsibility for the new photoelectric pyrometer the development of expanded pyrometric calibration services. Booker and Waters have been assigned to this Group.

In order to ensure the relevance and effectiveness of these expanded programs, the Division has requested the Council for Optical Radiation Measurements (CORM) to update its 1982 report on "Pressing Problems and Projected National Needs in Optical Radiation Measurements". CORM has responded by establishing a task force to develop project proposals for implementation by our Division and ranking them by degree of need, appropriateness, probability of success, and urgency of need. The task force report is expected to become available in October 1985 and will be given prime consideration in formulating our future plans.

Our commitment to explore new technologies through basic research, and to apply the results to our metrology mission, remains unchanged. The rapidly expanding use of electro-optical devices in communication, instrumentation, and information processing has created calibration needs that are not being met in a cost-effective manner by traditional approaches. These needs are surfacing in a variety of commercial applications, in DOD weapons systems and countermeasures programs. We are responding to these needs by developing a body of scientific knowledge to support the establishment of photodetector standards for visible, near ultraviolet and near infrared radiometry. This is achieved by (1) conducting key experiments to identify the physics pertinent to the performance of standard photodiodes, (2) developing theoretical models of photodiode performance that

incorporate the pertinent physics, and (3) developing innovative processing steps and novel photodiode structures based on the predictions of the theoretical models. A significant portion of this work is carried out in collaboration with other national standards laboratories, universities, and industrial contractors.

Our staff continues to be engaged in numerous interactions with standardizing laboratories, professional societies and voluntary standards organizations at the national and international levels. For example:

- The Radiometric Measurement Services and Photodetector Physics and Metrology Groups are participating in international intercomparisons organized by the Consultative Committee on Photometry and Radiometry (CCPR) to evaluate the effectiveness of the 1979 redefinition of the candela. During FY 1985, the Division completed initial measurements of intercomparison lamps and completed the design and construction of intercomparison detector packages.

- Several Division employees serve on international committees, such as the International Commission on Illumination (CIE), which are concerned with the development of new measurement methods and standards for radiometry and spectrophotometry.

- The exchange program between our Division and the Physikalisch-Technische Bundesanstalt (PTB) of the Federal Republic of Germany continued in FY 1985. Drs. Moestl and Stock from the PTB Radiometry Laboratory pursued topics of detector physics in our laboratories, and Robert D. Saunders is currently working at PTB on topics of absolute radiometry. The purpose of these exchanges is to make each institution thoroughly aware of the instrumentation and measurement technology used by the other.

As in previous years, a number of guest scientists have worked with us on projects of mutual interest:

Dr. Joaquin Campos Acosta from the Institute of Optics in Madrid, Spain, worked on setting up a CO_2 laser-based detector characterization facility for the infrared.

Messrs. Sheng-Tsong Chang and Chang-Long Chang from the National Science Council of Taiwan participated in the development of spectrophotometric standards.

Dr. Gyorgy Eppledauer from the Institute for Technical Physics of the Hungarian Academy of Science worked on the self-calibration of silicon photodiodes.

Professor He Ming-Gao from the Institute for Electric Light Sources of Fudan University, Shanghai, PRC, collaborated on the intermediate laboratory support program for geometrically-total spectral flux.

Dr. Henry Kostkowski, Spectroradiometry Consulting, McLean, VA, and Dr. Judith Lean, University of Colorado, characterized and calibrated a spectroradiometer for rocket-borne measurements of solar spectral irradiance in the 120 to 400nm region of the ultraviolet spectrum (in collaboration with Divisions 531 and 533).

Drs. Klaus Moestl and Klaus Stock from the Physikalisch-Technische Bundesanstalt in Braunschweig, FRG, performed studies of silicon photodiode stability.

Mr. Fred Nicodemus, Catholic University of America, Washington, DC, edited the Self-Study Manual on Optical Radiation Measurements.

Mr. Yoshihiro Ohno of the Matsushita Electric Industrial Company in Osaka, Japan, worked on characterizing the throughput of small integrating spheres for measurements of geometrically total luminous flux.

Dr. Zhang Rui-Rong of the Shanghai Institute of Technical Physics, PRC, undertook a study of silicon photodiode stability.

Their valuable contributions to our programs are acknowledged with thanks.

SPECTRORADIOMETRY AND OPTICAL PYROMETRY (E. F. Zalewski, K. D. Mielenz)

The Spectroradiometry and Optical Pyrometry group performs research to utilize the most promising advancements in radiometric technology. The main output of the Group is the development of new instrumentation and techniques for radiation thermometry (optical pyrometry) and for the spectroradiometry of sources and detectors of optical radiation. In addition, the group performs special tests of calibrations to assist the radiometric community (most often other government agencies) in the area of high-accuracy radiometry.

Pyrometry

The most significant change in this program has been the redirection of its immediate goal to that of producing an instrument strictly for pyrometry lamp calibrations and temperature scale realizations. The experiment to compare the freezing points of silver and gold was turned over entirely to the optical-fiber-thermometry project to allow the new pyrometer to be brought on-line to relieve the overburdening of FASCAL (Facility for Automatic Spectroradiometric Calibrations). Waters will comlete the first lamp-to-lamp comparison calibrations and the instrument will be transferred to the Measurement Services Group before the end of FY 85.

To meet the needs of the infrared radiation thermometry community, Popenoe and Yokley are working on a project to build new types of blackbody standards utilizing heat-pipe technology. Two types of heat-pipe blackbodies are under construction: a sodium-filled one to cover the temperature range from 500C to 1100C, and a mercury-filled one to cover 200C to 350C range. The heat-pipe is designed to assure that the cavity temperature is the same as that sensed by the thermocouple or other contact thermometer in another area of the heat-pipe. In addition, the heat-pipe effect enables the construction of high-emissivity cavities having a reasonable large size aperture. After testing and evaluation of the quality of these blackbodies, they will form the basis for a proposed facility to calibrate radiation temperature, spectral radiance and spectral irradiance of infrared sources.

During this past year, Zalewski organized a one-day session of the CORM meeting that focused on pyrometry and infrared radiometry. This session brought together for the first time the radiation thermometry community and CORM, and also strengthened the realtionship between the radiation thermometry community and the Radiometric Physics Division. The meeting emphasized the need for ir radiation temperature standards and a more active role for NBS in this area. At present NBS is routinely providing a measurement base for visible pyrometry only. There is hope for

some improvement in ir radiation thermometry stemming from the project to develop blackbody standards using heat pipe technology, but what is needed is a complete program at NBS headed by a senior staff member with a solid background in radiometry and thermometry.

The ASTM committee on radiation thermometry has undertaken a project to write a manual on how to use radiation thermometers correctly. Zalewski has become active on this committee and is contributing to two of the chapters in this book: one on the conceptual basis of the measurements and the other on standards and calibration practice.

Absolute Determination of Gold Point

Preparations for an experiment using absolute radiometry to measure the melting point of gold were begun by Saunders and Shumaker during the summer. All of the NBS spectroradiometric scales are currently based upon the gold point and the present assessment among national laboratories is that this temperature (1337.6 K) is uncertain by about 0.5° (corresponding to a radiometric uncertainty of roughly 0.5% in the visible). The planned experiment is much more direct than the few previous links between absolute radiometry and the temperature scale, and should significantly improve the present comparison uncertainty of about 1°. At the heart of the experiment is a laser-irradiated integrating sphere whose exit port radiance will be calculated from irradiance measurements made, redundantly, with both an absolute silicon diode and an electrically calibrated radiometer (ECR). This radiance will then be compared with that of a blackbody at the gold point using a spectroradiometer. A new heat-pipe, gold-point furnace has been constructed with an easily interchangeable crucible so that geometrical parameters can be changed to permit some verification of the cavity blackness. The necessary lasers have been acquired and the characterization of the spectroradiometer (slit function and linearity measurements) has been begun. The characterization of the ECR is being started by R. D. Saunders while a guest worker at PTB this fall.

Infrared Radiometry

Yokley and Ward completed the calibration of a variable (near ambient temperature ir source in an experiment that also intercompared two blackbody standards. One of these had been built by Yokley for the Air Force Metrology Lab and was of a design similar to the NBS standard to which it was compared. A temperature difference of 0.2°C (at 50°C) was observed. This difference was larger than the expected uncertainty in the blackbodies and is most likely due to the ir radiometer used to intercompare the blackbodies. Characterization experiments on the radiometer prior to the blackbody intercomparison showed a rather large field-of-view error. Since the radiometer was Navy property and designed for field

applications, it was not suitable for high-accuracy work nor was it possible to carry out extensive modifications. Future work in the ir should focus on optimization of a radiometer specifically for calibration purposes.

Work on extending our ir detector calibration capability was begun. Thomas completed a series of measurements to extend the calibration range of several ECPRs (electrically calibrated pyroelectric radiometers) to 3.4μm. A radiant power intercomparison of the ECPRs at this wavelength showed agreement to within 1%. The ir calibration factors of the ECPRs agreed to within the precision of the radiometers.

Other work on extending our ir detector calibration capability to the 10μm region is now underway. Dr. Joaquin Campos, a guest worker from the Institute of Optics in Madrid, is setting up a CO_2 laser based detector characterization facility in collaboration with Belzer and Brubaker. The initial experiments planned for this year are to measure the linearity and absolute response of a commercially available ir detector (HgCdTe and/or pyroelectric).

Spectroradiometry

For the past dozen years the NBS spectral irradiance scale has been derived from the spectral radiance scale by a method which, in its extension into the infrared, is limited to about 1.6 micrometers because of inadequate signal levels at longer wavelengths. During 1985, Saunders, Shumaker, and Walker developed a new technique which overcomes this difficulty and permits the realization of the spectral irradiance scale to 2.5 micrometers. It involves the use of a lamp-irradiated integrating sphere with a carefully measured exit port area. Measurement of the exit port spectral radiance then permits this sphere source to be used as a source of known spectral irradiance. The first routine lamp calibrations on FASCAL using this technique are scheduled for October 1985.

Last year, we reported on a project to design a calibration procedure for x-ray film sensitometry for the National Center for Devices and Radiological Health (NCDRH). A prototype exposure meter devised by Zalewski and Hattenburg was delivered to the NCDRH and demonstrated to be a significant improvement over the calibration procedure they were currently using. An improved version of the exposure meter was built by Brubaker based on an integration circuit designed by Fowler and Campos. Brubaker and Hattenburg demonstrated this final version at the NCDRH. The result was a decrease in the time required to perform the calibration from hours to minutes, plus approximately an order of magnitude increase in measurement precision. The project leader at NCDRH commended this extremely significant contribution to the NCDRH effort to reduce patient x-ray exposure levels.

The project to examine the feasiblity of using a pulse dye laser (PDL) to measure the relative spectral response of a narrow band radiometer was completed this year by Campos. He did a complete characterization of the PDL and the pulse response characteristics of the detectors. The limitations on the measurement were due to the characteristics of the particular PDL being used: the variability in its wavelength setting and the large amount of background (fluorescence) radiation in the PDL output. These conclusions were tested by comparing the PDL based spectral response measurements to those based on much higher accuracy cw dye laser techniques. Agreement was within the expected level of uncertainty. However, these experiments showed that a significantly better (more expensive and non-transportable) PDL would be required to do narrow-band spectroradiometer calibrations at an acceptable uncertainty level.

An equipment failure on FASCAL during this year required that Popenoe redesign some of the instrumentation because of the unavailability of replacement parts.

Photodetectors

Houston and Saunders completed the development of the Division's new detector spectral response comparator and placed the instrument into operation in 1985. It consists of an argon mini-arc, a prism-grating double monochromator with 0.01 nm resolution, and a mirror system to collect, monitor, and image the output beam onto the test detector. The new instrument has been used to put the detector calibration (DRIP) program on a routine basis, resulting in a significant reduction of calibration turnaround times. It was also used to perform research measurements for the Photodetector Physics and Metrology Group, as discussed in that Group's report.

Thomas performed characterization measurements on the second generation 100% quantum efficient devices (QED-200) recently introduced by the United Detector Technology Company. The design changes were suggested by Zalewski and Duda (UDT Co.) in their original publication describing these devices. Significant improvements in field of view, spectral range, polarization insensitivity and ease of alignment were achieved. This device has been recognized as one of the significant new commercial developments of 1984. NBS and UDT will jointly receive the IR-100 award for this work.

Belzer completed the design and construction of the circuit boards for the CCPR/CIE intercomparison detectors. Belzer and Bruhaker completed the mechanical drawings for the detector housing and the construction of the prototype. Testing of the prototype was completed by Booker and Cornett (summer employee engaged in the optical fiber thermometer

project). Delivery of the remaining detector housings, however, is several months behind schedule. As soon as the housings are received construction of the intercomparison detectors can be completed and the intercomparison measurements initiated. It is hoped that the first stage of the intercomparison will begin by November.

Thomas has taken up the project to analyze the DRIP intercomparison data. This was a project, started by Warren Gladden before he left the Division, designed to diagnose measurement problems of NBS detector calibration customers. Dr. Zhang, a guest worker from the Shanghai Institute of Technical Physics, and Belzer have undertaken a study of silicon photodiode cleaning techniques and reflectance stability.

SPECTROPHOTOMETRY (J. J. Hsia)

The Spectrophotometry group is responsible for:

(1) Establishing and improving high-accuracy spectrophotometric and densitometric scales in the National Measurement System by developing new instrumentation, establishing new measurement capabilities, and improving basic standards.

(2) Disseminating these scales by developing transfer standards and standard materials, establishing measurement assurance programs, performing calibration services, and providing consultation to the measurement community.

(3) Studying and developing new methods for radiometric characterization of optical media and components for scientific research and for emerging technologies.

FY 1985 has been another productive year of the Group. Major accomplishments in measurement services, spectrofluorimetry, infrared spectrophotometry, optical densitometry, and standards committee work were made as presented below.

Measurement Services

Patricia Barnes, who joined the Group in August 1984, and Weidner provided special calibration of spectral transmittance, spectral specular reflectance, and spectral diffuse reflectance. They also produced aluminum-mirror, specular-reflectance SRM's. Eckerle provided measurement assurance for retroreflectance, a new measurement service.

A new Standard Reference Material No. 2034, holmium oxide in perchloric solution, was developed by Weidner, Mavrodineanu, Mielenz, Velapoldi, Eckerle, and Adams. The SRM was produced by Weidner, Mavrodineanu and Barnes. It is to be used to calibrate the wavelength scale of spectrophotometers from 241 to 640 nm.

A new measurement assurance service for transmittance was established by Eckerle, Hsia, and Weidner. This service assesses the accuracy of spectral transmittance measurement capabilities from 92% to 0.1% in the visible spectral region.

Weidner initiated and started research on oxide mixtures as wavelength standards for spectral reflectometers in the near infrared range.

To facilitate the dissemination of spectrophotometric scales, Hsia and Mielenz participated in the CORM/NBS task force on intermediate laboratories. The task force specifies and ranks needs for transfer standards and calibrations to be supplied by intermediate laboratories, and identifies private laboratories that can serve as intermediate calibration laboratories for spectrophotometry.

Spectrofluorimetry

The goal of this project is the performance assessment of instruments for fluorescence measurements in non-destructive testing, appearance measurements, and analytical chemistry. The main efforts are to develop the NBS reference spectrofluorimeter and to develop standard materials.

Eckerle and Chang, a guest worker from the Taiwan National Science Council, characterized the reference spectrofluorimeter for wavelength accuracy, stray radiant energy, and linearity. They measured its relative spectral response by two methods - using an NBS tungsten-strip standard lamp, and an NBS standard silicon photodiode. Preliminary technical emission spectra for quinine sulfate dihydrate were obtained.

A commercial fluorimeter was purchased and modified to conform to ASTM standards. An ASTM round-robin test to evaluate three liquid dye penetrants was performed in collaboration with L. J. Swatzendruber, CMS. Solutions of different concentrations were measured, and thermal and ultraviolet fading tests were done.

Infrared Spectrophotometry

The purpose of the long-wavelength infrared spectrophotometry project is to establish IR measurement services from 2.5 to 25μm for transmittance, diffuse reflectance and specular reflectance. This is done through the development of an LWIR spectrophotometer and studies of the principles and practices of Fourier transform spectroscopy (FTS).

Weidner designed and installed support systems for the Fourier scanning interferometer spectrometer and the specular and diffuse reflectometers attachments. This allows the spectrometer to be moved along a five-foot track so that the collimated infrared beam can enter either the specular reflectometer or the diffuse reflectometer. These reflectometers were assembled and enclosed so that the system can be purged of water vapor and carbon dioxide. The air-dryer filter system required for the purging is operational. The signal throughput of the specular reflectometer was tested with a liquid-nitrogen cooled HgCdTe detector (with detection surface facing down), and was found satisfactory. The detector for the diffuse reflectometer will be tested as soon as the proper high-pressure connections are completed and will allow ultra-pure

nitrogen gas to be supplied to the Joule-Thompson cryostat-HgCdTe detector through a filter. This second detector has its detection surface facing up. Once the connections are made, Weidner will test the signal throughput of the diffuse reflectometer. If this test is satisfactory, he will be ready to proceed with performance checks.

Cohen has completed a draft document, Introduction to Fourier Transform Spectroscopy. This simple, concise document is organized into three parts: a selective review of Fourier transform mathematics, a treatment of the physics of Michelson interferometry, and topics in Fourier transform spectroscopy. The next phase will be an analysis of the practical aspects of Fourier transform spectroscopy, as effected by actual operational factors.

Optical Densitometry

The project on optical-density measurements with an inverse-fourth instrument is progressing. In FY85, efforts by Popenoe and Fink included resolving the problem of the optical zero-offset distance, designing and constructing the opal-diffuser collecting system, and comparing opal-diffuser and integrating-sphere collection systems.

Through realignment of the optical system, refinement of the measurement procedure and modified software, the optical zero-offset distance is now a constant and is independent of the optical density of the filter employed.

To conform to the new ISO Standard 5/2-1985. ("Photography-Density Measurements - Part 2: Geometric Conditions for Transmission density"), an opal-diffuser collection system was designed and constructed. This system consists of an opal glass, a sample plate with grooves for applying vacuum and pressure, and a specular-aluminum-hemispherical collector for diffuse light.

Measurements of photographic and x-ray step tablets using both opal-diffuser and integrating-sphere collection systems were performed. Preliminary data indicated that, below optical density one, measurements made with the opal-diffuser gave lower optical densities than those made with the integrating sphere. These differences are expected since the opal diffuser introduces interreflections between the sample surface and the opal diffuser. These differences are consistent with measurements made by PTB, West Germany.

Fink continued to produce x-ray film and photographic step tablets used in the calibration of optical densitometers (OD from 0 to 4) and microcopy resolution charts for determining the resolving power of microscopy systems.

Standards Committee Work

During the past year, Cohen collaborated with ASTM committee E7.10.04 on infrared methods, particularly on the compilation of a glossary for ir thermography for NDT and a draft standard test method for minimum resolvable temperature difference (MRTD). Cohen's talks and publications have apparently motivated one major manufacturer of thermal imaging systems to provide more complete and meaningful performance specifications. His attempts to measure the spatial distribution of temperature of targets were unsuccessful owing to a malfunctioning spot radiometer. The measurements will be repeated pending the availability of a suitable instrument. It appears feasible to utilize CBT's laboratory facility for carrying out the objectives of this work.

Hsia was elected to the Board of Directors of the Inter-Society Color Council, an inter-disciplinary organization of more than 20 scientific, artistic and industrial societies which have common problems of color and appearance.

As an Associate Director of CIE Division 2 on Physical Measurement of Light and Radiation, Hsia has established three new committtees on fluorescence, retroreflectance, and gloss.

PHOTODETECTOR PHYSICS AND METROLOGY (J. GEIST)

During FY85, this Group was responsible for performing research to identify and develop new approaches to radiometric measurements and standards.

Detector Physics

A very accurate verification of the original self-calibration technique has been reported by Nigel Fox at the UK NPL. He self-calibrated two EG&G UV444B photodiodes at 676.4 nm to the best possible precision and compared them with an NPL transfer standard thermopile that had been calibrated against the new NPL Electrically Calibrated Cryogenic Cavity Radiometer (ECCCR). The estimated accuracy of the latter instrument is 0.01% with respect to the SI units and the self-calibration of both diodes agreed with the ECCCR based calibration to within 0.02%. This may be somewhat fortuitous, because there are some questions about the accuracy of self-calibration physics at this level. For this reason, Fox is preparing a more extensive intercomparison that will involve more wavelengths and more photodiodes, as well as direct comparison with the ECCCR, rather than comparison through a transfer standard.

This verification of silicon physics as a basis for radiometric calibration at the highest levels of accuracy highlights the importance of developing stable, 100% quantum efficiency Si based radiometers. The evolution of self-calibration is necessary if we are to disseminate spectral flux calibrations to the broadest user community with minimum complexity, expense and degradation of accuracy.

Toward this end, we have completed evaluation of the UDT QED 200 100% quantum efficiency radiometers. Their optical performance is excellent. They accommodate a sufficiently wide field of view to be used to calibrate the spectral power at the image of the exit slit of a monochromator, and they have a quantum efficiency of greater than 99.7% at 633 nm. However, the requirement of reverse bias to achieve 100% quantum efficiency remains inconvenient, and the flux level at which 100% quantum efficiency can be achieved may decrease with time. Both of these problems are associated with the inversion layer diode structure, which seems to provide only a limited solution to the problems of 100% quantum efficiency and stability of response after exposure to uv radiation. While other diodes lose their uv response with uv exposure, inversion layer diodes retain their high internal quantum efficiency throughout the uv and visible, but only at low flux levels. Exposure to uv and other forms of oxide stress, possibly including the passage of time, seem to convert strong inversion to weak inversion, thereby lowering the maximum flux level at which the inversion layer diodes remain linear in response.

Saunders and Houston have completed an experimental survey of the internal quantum efficiency of some commercially available silicon photodiodes and some experimental structures. They have discovered a number of devices whose internal quantum efficiency is within five percent of unity from 350 nm to 950 nm. Some of the same devices have maintained their high quantum efficiency during more than 24 hours exposure to 1 mW per square cm of 254 nm wavelength uv radiation.

The recent improvements in silicon fabrication technology that are evident from the results of the recent internal quantum efficiency survey, and the growing recognition of the problems with inversion layer diodes, make this an ideal time for the development of silicon photodiodes that are optimized for radiometric accuracy, precision and stability. During the latter part of FY85, we funded proposals from Advanced Detector Technology (ADT) in The City of Industry, CA, and United Detector Technology in Hawthorne, CA to investigate innovative processes for producing stable 100% quantum efficiency silicon photodiodes. The development of such devices would form the basis for producing substantially improved 100% quantum efficiency radiometers compared to those that can be built with inversion layer diodes.

Saunders and Houston have also discovered some not yet understood features in the ultraviolet internal quantum efficiency of some silicon photodiodes. To our surprise these features do not fit a model of the effect of the interaction of band gap narrowing and impact ionization in the depletion region near the oxide interface that we had derived near the beginning of FY85, and for which we had been searching. However, even though the model cannot explain the experimental results as a coherent whole, it does predict the location of both features, but this may be a coincidence. Klaus Stock from West Germany's PTB pursued this topic while a guest worker in the group during FY85, but was not able to shed any more light on the phenomena during his short stay. He did, however, help us to develop improved experimental tools for investigating the phenomena further.

Developments in the germanium spectral region have been disappointing. The Purdue Ge photodiode design was optimized based on the results obtained last year, and a new diode was fabricated at Purdue and tested at the University of Arizona. The optimized diode shows no substantial improvement in performance over the previous design. A second batch was fabricated but was ruined during fabrication, highlighting the serious difficulties in the fabrication of Ge diodes.

A contract was let with EPITAXX, a new company in Princeton, NJ, for large-area InGaAs/InP heterostructures as a possible substitute for Ge in this spectral region, since these devices have the same bandgap as Ge. One device was delivered and is in the process of being tested. Based on the long delivery times for incomplete orders, there appear to be fabrication problems with these devices as well.

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From Peter Key of the UK NPL, we learned of a very promising Ge device that was formerly produced by Electro-Optical Systems Specialists in Berwyn, PA. This device had such a high external quantum efficiency that it seems its internal quantum efficiency must be nearly unity down to 600 nm, but it exhibited a saturation non-linearity at so low a flux level that Key and others thought it unsuitable as a standard diode. Actually, the non-linearity is a symptom of a problem that can probably be solved without sacrificing high internal quantum efficiency, if ever the latter is achieved. At our suggestion, Key is in the process of trying to demount this diode to allow a direct measurement of its internal quantum efficiency. In the meantime, we are starting discussions with Electro-Optical Systems Specialists about custom radiometric quality diodes.

Turning to a new area of detector research of interest to the Group, we note that self-calibration may prove a useful tool for the Low Background, Long Wave Infrared (LBLWIR). Mike Petroff at Rockwell International in Anaheim recently developed a model of the internal quantum efficiency of Blocked Impurity Band Infrared Detectors (BIBID) that operate near liquid-helium temperature in the 5 to 30 μm spectral region. There are many similarities between intrinsic silicon photodiodes in the visible and BIBID detectors operating in the LBLWIR, and these similarities suggest the possibility of self-calibration. Like our silicon self-calibration model in the visible, Petroff's model depends upon a small number of physically meaningful diode parameters, and the shape of the relative spectral response determines the absolute value of the spectral response at every wavelength. This is the key to self-calibration.

To test the feasibility of BIBID self-calibration, we have developed a non-linear fitting program using a simplex algorithm to adjust the parameters in Petroff's BIBID model to experimental relative spectral response data. We expect that the program will determine the absolute spectral response of a BIBID response values as a function of oxide bias at a single wavelength. This program will be tested with simulated spectral response data to determine the optimum set of values for the wavelength and oxide bias, and the results will be used to design an experimental protocol for an intercomparison between BIBID self-calibration and a blackbody based calibration. Both the experimental protocol and the fitting program will be sent to Lum Eisenman at the Naval Ocean System Command for use in the first intercomparison involving BIBID self-calibration.

Next year we hope to embark on a program of fundamental research into BIBID physics as well as to expand our current research into the fundamental physics of intrinsic silicon photodiodes through the acquisition of Dr. Jerry Lowney as a new group member. He is a theoretical/computational solid state physicist with a great deal of experience in the physics of semiconductor band edges, deep levels, and the oxide/silicon interface. This experience matches our interests in BIBID physics, bulk region recombination and interface recombination, respectively. He also has a fair amount of laboratory experience, and his forte is modeling and interpreting experimental data.

Spectral Radiometry

In a recent private communication, Fox reported filter transmission uniformity measurements with the 676.4 nm line of a Krypton ion laser that are about a factor of five better than those obtained by Schaefer a few years ago using tunable ring laser radiation. The filter was custom made by a German firm using wedged glass substrates manufactured in the UK NPL Optical Shop. The exterior filter surfaces were coated with anti-reflection coatings. The improved filter uniformity could represent a new state-of-the-art in the development of commercial interference filters, or could be an artifact of the larger line width of the Kr ion laser. Fox has given one of these filters to Schaefer for measurements to resolve this question.

Due to staff limitations, little progress has been made on the Multiple Reflection Configuration Filter or the Michelson Interferometer Filter. Liang, a WAE employee, has made some progress in developing a more realistic computer model of the Michelson Interferometer Filter, but he has not been available for this project since May. Schaefer developed a technique for aligning the Multiple Reflection Configuration Filter and made some multiple reflection measurements on first surface metalized mirrors to demonstrate the technique. Unfortunately, he could not make these same measurements on the potential Multiple Reflection Configuration Filter coating on the laser gyro mirrors that he obtained from OCLI, because the coated area did not come near enough to the edge of the filter substrate to support the multiple reflection configuration. Schaefer also measured the reflectance of the short wavelength band edge of the potential Multiple Reflection Configuration Filter coating with a single reflection using dye laser radiation and found that eight reflections would produce a satisfactory band pass shape.

Radiometric Instrumentation

There has been a growing desire within DOD and NASA for our group to become the Government's "in-house" center of expertise for photodiode measurement and calibration technology. To take on this role requires that we expand the scope of our interests in certain directions, while restricting the scope in other directions. We must start to consider how to achieve high accuracy and precision at very low flux levels as well as at the moderate levels that were our only concern previously, and we must consider new spectral ranges. As a consequence of this new focus, we will probably have to leave the development of spectral analyzers that are optimized for use with self-calibrated detectors to other groups, due to a lack of resources.

To implement the group's changing role, we have first to achieve the current state of the art in a number of detector technologies and build new characterization facilities to test the level of precision and accuracy available from these technologies.

In this connection, Schaefer and Tobin are assembling an ultra-high precision radiometer characterization facility that is designed to study the stability of radiometers at the parts per million level over periods from seconds to weeks. Schaefer is also acquiring the current state-of-the-art of measurements at liquid nitrogen temperature, and is designing an apparatus with which to carry out precision studies as a function of temperature based upon commercial Joule-Thompson micro- miniature refrigerators.

Schaefer is also collaborating with Dr. A. Young of San Diego State University and Dr. W. Borucki of NASA Ames Lab, to develop a prototype stellar radiometer which will be used to improve the state of the art of relative steller brightness determinations, and to search for extra solar planetary systems.

In the same connection, Fowler is planning a facility for electronic characterization of diodes, array elements and amplifiers. The purpose of this facility will be to support accurate measurements of current vs. voltage (IV), capacitance vs. voltage (CV), noise, and electronic gain of radiometric devices, for correlation of these characteristics with device performance.

Fowler and Tobin are also in the process of setting up an apparatus for dynamic linearity measurements on detectors under simulated waveforms. This instrument is based upon our earlier experience with this type of measurement in support of the NASA Langley Research Center's Differential Absorption LIDAR (DIAL) program.

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Water Bath Blackbody

During FY85, Fowler designed and constructed a water bath black body for the 5 to 60 degree temperature range. It is based on a circulating water bath and incorporates computer control and a level of self-calibration capability. Fowler modified the bath by moving the refrigeration coils closer to the heater for better temperature control, and by mounting a 4 inch diameter, black body cavity in the wall of the bath.

The bath is controlled by the circuitry provided by the manufacturer, but the temperature of the bath is measured by a high accuracy thermistor under computer control. The user inputs the desired control temperature, and an acceptable temperature tolerance range to the bath. Whenever the bath temperature drifts out of the tolerance range, the computer changes the set point in the bath control circuitry. This effectively increases the long term stability of the bath well beyond what was available from the commercial product. The computer also records whether or not the bath temperature is within tolerance at any given time on the RS-232 port, and records the periods when it is out of tolerance and the maximum deviation during each period on a disk file.

The system is calibrated in SI thermodynamic temperature units by removing the thermistor from the bath, placing it in small freezing point cells that are provided with the system, and recording the voltage drop across the thermistor during a freeze. One of the freezing point cells contains ice water, and the other two are available from NBS as Standard Reference Materials. When calibrated in this way the thermistor is capable of temperature measurements that are accurate to within 2 mK over the 0 to 60°C range. However, other sources of error, such as the temperature uniformity of the water around the black body cavity, will limit the current version of water bath to somewhere between 10 and 30 mK accuracy. In closing, we note that we may not be able to carry out work of this nature in the future due to our expanded role in photodiode physics.

RADIOMETRIC MEASUREMENT SERVICES (D. A. McSparron)

This Group provides a firm measurment base for the Nation's optical radiation community (defense and aerospace, instrument manufacturers and commercial calibration laboratories, lighting and photographic industries, research institutions, etc.). To accomplish this objective, the Group:

(1) Maintains measurement scales and provides, improves and extends NBS calibration services for the basic pyrometric, radiometric, and photometric quantities: radiance temperature, spectral radiance, spectral irradiance, detector spectral responsivity, luminous intensity, luminous flux, and color temperature.

(2) Engages in activities such as intercomparisons, measurement assurance programs, intermediate laboratory support programs, consultations and ad hoc experiments that will insure that measurments made in laboratories outside NBS have acceptable levels of accuracy.

The continuing effects of the failure of the NBS high-accuracy photoelectric pyrometer have dominated the calibration activities of the Group. The interim procedures instituted last year to allow calibration of pyrometric strips lamps on FASCAL have been refined by Walker to improve efficiency, although pyrometric calibrations continue to occupy about 25% of the available time. Direct public calibration billings for pyrometry, spectroradiometry, and photometry increased by about 25%. Again this year, Jackson performed a substantial amount of spectral irradiance calibration work in support of NASA/NOAA solar monitoring programs, notably the Solar Backscatter Ultra Violet (SBUV) Radiometer program. This other-agency calibration work also shows an increase of about 25% in comparison to FY 1984.

At the 1982 meeting of the Consultative Committee on Photometry and Radiometry (CCPR) plans were formulated for an international intercomparison of the photometric units of luminous intensity and luminous flux. These intercomparisons are of particular interest, since they will be the first attempt to evaluate quantitatively the effects of the recent redefinition of the photometric units. During the current year, NBS completed the initial measurments on the intercomparison lamps and submitted them to the International Bureau of Weights and Measures. In FY-86 the lamps will be returned to NBS for remeasurement and it is expected that result will be available in the summer of 1986.

Significant progress was made in the filter radiometry project to realize photometric scales by means of absolute silicon detectors and interference filters. Mr. Bruening worked at the Egyptian Standards Laboratory (NIS) for a month completing the joint effort that brought

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Egyptian scientists to NBS the previous year. While in Egypt, measurements necessary for realizing photometric scales were performed with an accuracy of +4%, -2% in the center of the visible. This demonstration completed the joint project with NIS. The work at NBS was continued with the spectral calibration of an incandescent lamp. The agreement with the blackbody-based scale was at the ±2% level. In the process of characterizing the commercial detectors used in this work, several areas for improvement were noted. These suggestions were passed on to the manufacturer and have resulted in changes in the production process.

The intermediate laboratory support program for geometrically-total spectral flux is now well underway. The goal of this program is to develop a sustained source of photometric standards with rapid accessibility. The program was initiated in response to the Fourth CORM Report and is being coordinated with the Lamp Testing Engineers Conference (LTEC). One or more commercial laboratories will maintain close ties with NBS through measurement intercomparisons and will undertake to generate standards for lamp types not normally available from NBS. Validation of measurement capability for spectrally rich sources will require the NBS supply incandescent and one non-incandescent, standards of spectral flux. Ward was assigned full time to the incandescent phase of this project in January, and has completed the rebuilding of the gonio-spectroradiometer; procurement, modification, and seasoning of suitable lamps; and is well along towards the full characterization of the instrument. It is projected that lamps will be available for issuance to the industry in December, 1985. The second year work of the project, on high pressure sodium lamps, is well ahead of schedule thanks to the efforts of He Ming-Gao, a guest scientist from Fudan University, Shanghai, China, and Joseph Kepple, a summer student from Butler College. Appropriate ac electrical circuitry for operating the lamps has been setup and checked out, a lamp seasoning rack has been constructed, and the check out of a spectroradiometer has begun. The completion of the total project by the end of FY-86 seem well in hand.

Mr. Ohno, a guest scientist from Matsushita Electric Industrial Company, Osaka, Japan, has made substantial progress in his project to explore alternatives to goniometry for generating geometrically-total flux standards. The concept of using a small integrating sphere whose throughput has been spectrally characterized and which is calibrated with an external source has been explored in a computer modeling study. The results of this modeling study indicate that an accuracy of a few tenths of a percent may be achievable with this approach. An experimental program to verify these very encouraging results has begun and is expected to be completed in the first quarter of FY-86.

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SPONSORED CONFERENCES

Division 534, Radiometric Physics

Thirty-third National Infrared Information Symposium, May 14-16, NBS, Gaithersburg, MD

Council for Optical Radiation Measurements, NBS, Gaithersburg, MD, May 29-30, 1985.

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INVITED TALKS

Division 534, Radiometric Physics

J. Geist, "Silicon Photodiode Physics as a Basis for Accurate Radiometry", Invited Lecture Tour of People's Republic of China, State Bureau of Metrology - Chengdu and Shanghai, April 10 - April 28, 1985.

J. Geist, "Historical Introduction to Radiometry", and "Modern Electo-optical Technology and Radiometry", Invited Lecture Tour of People's Republic of China, State Bureau of Metrology - Beijing, April 11-12, 1985.

J. Geist, "Silicon Photodiode Physics as a Basis for Accurate Radiometry", Tranducers '85, 1985 International Conference on Solid-State Sensors and Actuators, Philadelphia, PA, June 11-14, 1985.

J. Geist, "Physics of Silicon Photodiode Self-Calibration", and "Conference Summary", International Meeting on Advances in Absolute Radiometry", and "Conference Summary", Cambridge, Mass., June 24-25, 1985.

J. J. Hsia, "Bidirectional Reflectance Distribution Function (BRDF) Measurement Methods - An Overview of Gonio-spectrophotometry", Invited Lecture Tour of People's Republic of China, State Bureau of Metrology - Beijng, Chengdu, and Shanghai, April 10 - April 28, 1985.

J. J. Hsia, "Philosophy and Establishment of U.S. National Scales in Spectrophotometry", Invited Lecture Tour of People's Republic of China, State Bureau of Metrology - Beijng, Chengdu, and Shanghai, April 10 - April 28, 1985.

J. J. Hsia, "NBS Standard Reference Materials in Spectrophotometry and Densitometry", Invited Lecture Tour of People's Republic of China, State Bureau of Metrology - Beijng, Chengdu, and Shanghai, April 10 - April 28, 1985.

J. J. Hsia, "Current Technical Activities on Spectrophotometry in the U.S. Standard Organizations and Societies (ASTM, ISCC, ANSI)", Invited Lecture Tour of People's Republic of China, State Bureau of Metrology - Beijng, Chengdu, and Shanghai, April 10 - April 28, 1985.

J. J. Hsia, "Current Technical Activities on Spectrophotometry in the International CIE Standard Organization", Invited Lecture Tour of People's Republic of China, State Bureau of Metrology - Beijng, Chengdu, and Shanghai, April 10 - April 28, 1985.

A. R. Schaefer, "Development of Quantum-Perfect Detectors", Space Science Division Astrophysics Seminar Services, NASA Ames Research Center, August 13, 1985.

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Division 534, Invited Talks (cont's)

E. F. Zalewski, "Implementation of the Silicon Photodiode Self-Calibration Procedure", Atmospheric and Environmental Research, Inc., Cambridge, Massachusetts, June 24, 1985.

E. F. Zalewski, "Radiometry's Holy Grail: 100% Quantum Efficient Detectors", Optical Society of America, Local Chapter, Washington, DC, April 17, 1985.

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PUBLICATIONS

Division 534, Radiometric Physics

Eckerle, K. L., Hsia, J.J. and Weidner, V. R., Transmittance MAP Service, NBS Spec. Pub. No. 692, 1-44 (March, 1985).

Eckerle, K. L., Chang, S. and Hsia, J.J., Calibration in 1976 and 1983 of Didymium Glass Filters Issued as NBS Standard Reference Materials, Color Res. Appl. 10 (1), 32-37 (Spring 1985).

Hattenburg, A. T., and Shumaker, J. B., Linearity Study of a Diode Array Radiometer, Applied Optics Letter, 23, 3257 (1984)

Keller, R. A., Warner, B.E., Zalewski, E.F., Dyer, P., Engleman, R. Jr., and Palmer, B.A., The Mechanism of the Optogalvanic Effect in a Hollow-Cathode Discharge, J. de Physique, 44, C7-23, (1983).

Lowney, J. R., and Geist, J., Comparison of Models of the built-in Electric Filed in Silicon at High Donor Densities, J. Appl. Phys. 55, 3624-3627 (1984).

Popenoe, C. H., and Hsia, J. J., Optical Density Determination with an Inverse-Fourth Instrument (Technical Activities 1984, NBSIR 84-2944, November 1984).

Richmond, J. C. and Nicodemus, F. E., Self-study Manual on Optical Radiation Measurements Part I--Concepts, Chapter 12, Blackbodies, Blackbody Radiation, and Temperature Scales, NBS Technical Note 910-8, April 1985.

Saunders, R. D. and Shumaker, J. B., An Automated Radiometric Linearity Tester, Applied Optics, Vol. 23, 3504, October 15, 1984.

Schaefer, A. R., Photodiodes for Astronomical Stellar Radiometry, Proc. of the Workshop on Improvements to Photometery, NASA Conference Publication 2350, November 1984.

Schaefer, A. R., Saunders, R. D., and Hughey, L. R., Intercomparison Between Independent Irradiance Scales Based On Silicon Photodiode Physics, Gold Point Blackbody Radiation, and Synchrotron Radiation, Proc. SPIE 499, 15-23 (Fall 1984).

Weidner, V. R., Hsia, J. J., and Adams, B., Laboratory Intercomparison Study of Pressed Polytetrafluorethylene (PTFE) Powder Reflectance Standards, Applied Optics, 24 (14), 2225-2230 (July 15, 1985).

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Weidner, V. R., Mavrodineanu, R., Mielenz, K. D., Velapoldi, R. A., Eckerle, K. L., and Adams, B., Spectral Transmittance Characteristics of Holmium Oxide in Perchloric Acid Solution, NBS Journal of Research, 90 (2), 115-125 (March - April, 1985).

Wilkinson, F. J., Farmer, A.J.D., and Geist, J., The Near Ultraviolet Quantum Yield of Silicon, J. Appl. Phys. 54, 1172-1174 (February, 1983).

Zalewski, E.F., and Gladden, W.K. Absolute Spectral Irradiance Measurements Based on the Predicted Quantum Efficiency of a Silicon Photodiode, Opt. Pura Y Aplicada, 17, 133 (1984).

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PUBLICATIONS IN PREPARATION

Division 534, Radiometric Physics

Dils, R. R., Geist, J., and Reilly, M., Measurement of the Silver Freezing Point with an Optical Fiber Thermometer: Proof of Concept, Journal of Applied Physics, (in press).

Geist, J., On the Possibility of Self-calibration of Blocked Impurity Band Detectors in the Low Background Long Wave Infrared.

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TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 534, Radiometric Physics

Robert L. Booker

Member, U.S. Panel of CIE TC-2.06 on Absolute Spectral Responsivity.

Member, U.S. National Committee of the CIE.

Julius Cohen

Member, ASTM E-07 Committee on Nondestructive Testing, Section E-07.10.04 on Infrared Methods.

Kenneth L. Eckerle

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittee E-13.03 on Infrared Spectroscopy, Subcommittee E-13.01 on Ultraviolet and Visible Spectroscopy, Subcommittee E-13.06 on Luminescence.

Jon C. Geist

Member IMEKO 10002 on Photon Detectors.

Jack J. Hsia

Associate Director, CIE Division 2 on Physical Measurement of Light and Radiation.

NBS representative, ANSI PH2 on Photographic Sensitometry and PH2-28 on Densitometry.

Member, ASTM D-1.26 Subcommittee on Optical Properties of Paint, Varnish, Lacquer and Related Products.

Member, ASTM E-12 Committee on Appearance of Materials (Spectrophotometry, colorimetry and geometric properties).

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittee E-13.01 on Ultraviolet and Visible Spectroscopy, E-13.03 on Infrared Spectroscopy, and E-13.06 on Molecular Luminescence.

Member, ASTM E-07.03 Task Group for Fluorescent Penetrant Measurement Standards.

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Division 534, Technical and Professional Committee Participation and Leadership (cont'd)

Jack J. Hsia (Cont'd)

Member, ASTM E-13 Committee on Molecular Spectroscopy Subcommittee E-13.01 on Ultraviolet and Visible Spectroscopy, E-13.03 on Infrared Spectroscopy, and E-13.06 on Molecular Luminescence.

Member, ASTM E-07.03 Task Group for Fluorescent Penetrant Measurement Standards.

Secretary, CORM/NBS Task Force on Spectrophotometry.

Secretary, National Capital Section of the Optical Society of America.

Donald A. McSparron

Consultant, CIE Technical Division II on Physical Measurement of Light and Radiation.

Member, ANSI Z311 on Photobiological Safety of Lamps.

Member, Illuminating Engineering Society (IES), Testing Procedures Committee.

Member, Lamp Testing Engineers' Conference.

Member, Infrared Calibration Standards Committee.

Klaus D. Mielenz

Secretary, U.S. National Committee of the CIE.

Secretary, CIE Division 2.

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittee E-13.06 on Molecular Luminescence.

Vice Chairman, CORM, TASK Force on Spectrophotometry.

Member, IES Committee on Nomenclature.

Robert D. Saunders, Jr.

Member, ANSI Z311 on Photobiological Safety of Lamps and Lighting Systems.

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Division 534, Technical and Professional Committee Participation and Leadership (cont'd)

Robert D. Saunders, Jr. (Cont'd)

Member, IES Committee of Photobiology.

Douglas B. Thomas

Member, ASTM Committee E44 on Solar Energy Conversion.

William R. Waters

Member, ASTM Committee E-20 on Temperature Measurement.

Edward F. Zalewski

Member, CIE Committee Div. 02 on Physical Measurement of Light and Radiation.

Member, U. S. National Committee of the CIE.

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STANDARDS COMMITTEE MEETINGS

Division 534, Radiometric Physics

Illuminating Engineering Society, Testing Procedures Committee, Spring Meeting, April 11-12, 1985, NBS, Gaithersburg, MD

Lamp Testing Engineers Conference, Spring Meeting, April 10, 1985, NBS, Gaithersburg, MD

ASTM, Radiation Thermometry, Commitee E-20, NBS, May 30-31, 1985

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STANDARDS WRITING

Division 534, Radiometric Physics

J. Cohen, Minimum Resolvable Temperature Difference for Thermal Imaging, ASTM E-07.10.04 on Infrared methods (Draft, April 1985).

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MAJOR CONSULTING AND ADVISORY SERVICES

Division 534, Radiometric Physics

J. Cohen provided consultation to Dag Holmsten of AGEMA, NJ and Harry Berger, Consultant, MD on thermal imaging and temperature profile.

J. Geist provided consultation to representatives of the U.S. Department of Energy on two proposals for novel temperature measurement techniques.

J. Geist provided consultation to representatives of the U.S. Aluminium Institute on a proposal for a novel temperature measurement technqiue.

J. Geist provided consultation to Rich Hansen of FIBREX Corporation on the optical design of high emittance refractory materials.

J. Geist provided consultation to Raj Khorda of United Detector Technology on the design of high quantum efficiency silicon photodiodes.

J. J. Hsia provided consultation to William M. Hell of NASA (Langley) on the flux averaging devices in the infrared spectral region.

J. J. Hsia provided consultation to Michael L. Rudolph (Rochester), Richard J. Byer (Rochester), and John C. Cloya (Wilmington) of DuPont on instrumentation and calibration of optical densities.

J. J. Hsia provided consultation to Mike Goodwin of Eastman Kodak on optical density of spectrophotometric measurements.

J. J. Hsia provided consultation to Sergei Jacobson of Israeli Air Craft Industries Co. on developing diffuse reflectometer.

D. A. McSparron served as a consultant to the Growth Chambers and Controlled Environments Working Group of the American Society for Horticultural Science on optical radiation measurements in plant growth chambers.

D. A. McSparron reviewed the "proofs of competency in photometric measurements" offered by the contractor to the University of Petroleum and Minerals, Dharan, Saudi Arabia, and advised UPM as to their adequacy and completeness.

A. R. Schaefer provided consultation to W. Boruchi of NASA Ames Research Center on the Design of multi-channel radiometers for extra solar planatory detection.

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Division 534, (Major Consulting and Advisory Services cont'd)

A. R. Schaefer provided consultation to Nigel Fox of the UK National Physical Laboratory on the use of ring dye lasers for accurate radiometry.

V. R. Weidner and J. J. Hsia provided consultation to Keith Snail of NRL, Washington D.C. and Herb Tardy of Sandia Laboratory on long wavelength infrared reflectometer instrumentation.

V. R. Weidner provided consultation to Richard S. Bodanes of NIH on absorptance measurements of hemato-porphyrin derivative (HPD), a complex mixture of photosensitizing porphyrins which is selectively retained in tumor tissue and used in cancer photochemotherapy.

E. F. Zalewski and D. A. McSparron advised the Office of Product Standards Policy on an appropriate U.S. position on a draft OIML specification for optical pyrometers.

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STANDARD REFERENCE MATERIALS

Division 534, Radiometric Physics

1. SRM 1001, X-Ray Film Step Tablet

   Used in the calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for Optical Densities from 0 to 4.

2. SRM 1008, Photographic Step Tablets

   Used in the calibration of optical densitometers and similar equipment used in the photographic and graphic arts fields. Certified for Optical Densities from 0 to 4.

3. SRM 1010a, Microcopy Resolution Tests Charts

   Used for determining the resolving power of microcopy systems.

4. SRM 2061, Reflection Step Tablets

   Used in the calibration of reflection densitometers and similar equipment used in the photographic and graphic arts fields. Certified for optical density from 0 to 2.

5. SRM 2019 and 2020, White Ceramic Tile for Directional-Hemispherical Reflectance from 250 to 2500 nm.
   SRM 2021 and 2022, Black Porcelain Enamel for Directional-Hemispherical Reflectance from 250 to 2500 nm.
   SRM 2015 and 2016, White Opal Glass for Directional-Hemispherical Reflectance from 400 to 750 nm.

   For use in calibrating the reflectance scale of an integrating sphere reflectometer.

6. SRM 2003b, First Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm.
   SRM 2011, First Surface Gold Mirror for Specular Reflectance from 600 to 2500 nm.
   SRM 2023, 2024, and 2025 Second Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm.

   For use in calibrating the photometric scale of specular reflectometers.

7. SRM 2009, 2010, 2013, 2014 Didymium-Oxide glass as Wavelength Standards between 400 and 760 nm.

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Division 534, Standard Reference Material (cont'd)

8. SRM 2034 Holmium oxide in Perchloric Acid Solution as Wavelength Standards between 241 and 640 nm.

MEASUREMENT ASSURANCE SERVICES

Division 534, Radiometric Physics

1. Transmittance MAP Service

   Provides a means for a laboratory to assess the accuracy of its spectral transmittance measurement capabilities from 92% to 0.1% in the visible region.

2. Retroreflectance MAP Service for Coefficient of Luminous Intensity

   Provides a means for a laboratory to assess the accuracy of its coefficient of luminous intensity measurement capabilities for bead sheeting and prismatic cube-corner retroreflectors and to assess the conformity to the spectral specification of its retroreflectometers.

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CALIBRATION SERVICES PERFORMED

Division 534, Radiometric Physics

Type of Service	Customer	SP250	Number of test	Income
Pyrometry		7.4 A thru G	32	$50K
	Defense & Aerospace		9	$20K
	Instrument & Cal labs		8	11K
	Lighting & Photography		5	6K
	Electrical & Materials		10	13K
Spectroradiometry		7.5 A thru J	38	70K
	Defense & Aerospace		18	32K
	Instrument & Cal labs		7	10K
	Lighting & Photography		2	6K
	Foreign		6	13K
	Electrical & Materials		5	9K
Photometry		7.7A thru R	12	30K
	Defense & Aerospace		4	16K
	Instrument & Cal labs		4	8K
	Foreign		2	3K
	Electrical & Materials		2	3K
Spectrophotometry		7.8 A thru I	29	22K
	Defense & Aerospace		3	2K
	Instrument & Cal labs		10	6K
	Lighting & Photography		3	2K
	Foreign		2	2K
	Electrical & Materials		11	10K
			111	172

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TRIPS SPONSORED BY OTHERS

J. C. Geist, Lecture Tour of the People's Republic of China, sponsored by Protocol Agreement between NBS and Chinese State Bureau of Metrology, National Institute of Metrology, Beijing; Institute of Measurement and Test Laboratories, Chengdu, Sichun Province; Shanghai Bureau of Metrology, Shanghai.

J. J. Hsia, Lecture Tour of the People's Republic of China, sponsored by Protocol Agreement between NBS and Chinese State Bureau of Metrology, National Institute of Metrology, Beijing; Institute of Measurement and Test Laboratories, Chengdu, Sichun Province; Shanghai Bureau of Metrology, Shanghai.

K. D. Mielenz, to represent the U.S. National Committee of the CIE at Executive Committee Meetings, sponsored by the Unites States National Committee of the Commission Internationale De L'Eclairage (CIE).

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SPONSORED SEMINARS AND COLLOQUIA

Division 534, Radiometric Physics

Dr. Fritz Riehle, "Recent Advances in Radiometry at BESSY", July 24, 1985, (Sponsored jointly with Division 533).

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TECHNICAL ACTIVITIES

Division 535, Radiation Source and Instrumentation

Task No. 15252 - Provide linac beam
Task No. 15253 - FASTBUS instrumentation specification
Task No. 15254 - Design, install and test microtron components

CW Accelerator Research (Microtron)

The NBS-Los Alamos joint project of "Research on CW Electron Accelerators Using Room-Temperature RF Structures" was started six years ago, with the goal of developing a technology base for CW electron accelerators. Many significant technical advances have been made as a part of this project, which is funded by DOE. Some of these, including the chopper/buncher system, side-coupled RF structures, end magnets, and beam profile scanners, have been recognized by the accelerator community by being copied or adapted for use in other accelerator systems. We presented eight papers describing our recent work on the racetrack microtron (RTM) at the Particle Accelerator Conference at Vancouver, B.C. in May 1985.

When the RTM is operating, it is expected to have many unique performance characteristics including the CW nature of the beam, the high current (up to 700 μA, consistent with maximum beam power of 100 kW), easily variable energy over a very wide range (~15 to ~220 MeV), excellent emittance, and very small energy spread (<4 parts in 10^4 at 185 MeV). These characteristics make the RTM a very valuable resource for a number of future research uses. Under present funding allocations we are estimating that construction of the RTM will be completed in June 1987. Following a period of accelerator physics research with the completed machine, it will be available for other research in late 1987.

In this report, we describe in detail the technical accomplishments of the project in FY 1985. It has been a highly productive and successful year. Highlights include: measurement of the 100 keV chopped beam emittance, which exceeds specifications; completion of installation of the entire 5 MeV injector linac system, with all RF power and drive; extensive field mapping of one end magnet, whose performance is excellent - far exceeding specifications; completion of construction of the 12 MeV linac for the microtron; installation of most of the control system, including the primary station; and first acceleration of beam by the injector linac.

An overall view of the RTM is shown in figure 1. The installation is complete with exception of: Phase II of the 5 MeV injection transport system; the 12 MeV linac and main axis beam line components; end-magnet vacuum chambers; recirculation return beam lines; and the extraction beam line.

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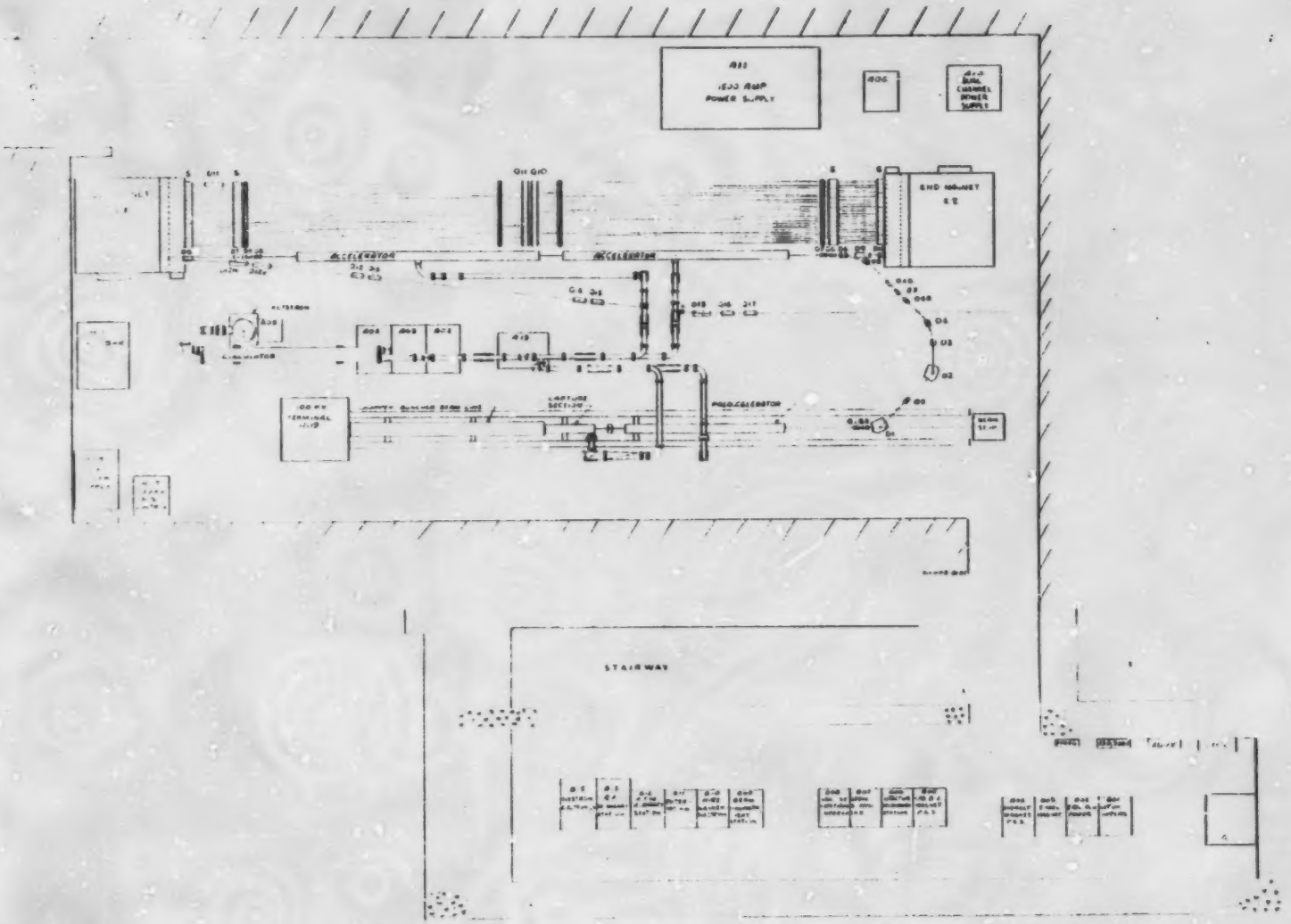

Figure 1 Plan view of the RTM.

Division 535, CW Accelerator Research (Microtron) (cont'd.)

A. Injector

1. Introduction

The injector consists of an electron gun in a 100 kV terminal, a 100 keV beam transport line, a 5 MeV injector linac, and a 5 MeV beam transport line. In FY 1985, the transverse emittance of the chopped 100 keV beam was measured and found to be consistent with the design value. The injector linac was used in tests of the RF system performance at Los Alamos. It was then moved to NBS, where it was installed, aligned, and put under vacuum with the 100 keV beam line. The injector stage of the RF system was assembled at NBS and tested with the injector linac. The first phase of the 5 MeV beam line (viz., the part required for injector linac performance tests) was installed, aligned, and put under vacuum. The control system was expanded to accommodate the injector linac, the injector RF system, and the first phase of the 5 MeV beam line. We have accelerated beam through the injector linac and measured its energy in the 5 MeV beam line.

2. 100 keV Beam Emittance Measurements

Measurements of the transverse emittance of the beam were made using three wirescanners temporarily located at the exit of the 100 keV beam line. The design value of emittance at this point is 5π mm•mrad. The results of the measurements are summarized in figure 2. The emittance of the dc beam is seen to be about 2π mm•mrad from 0 to 600 μA. This is well below the 4π mm•mrad limit imposed by the defining apertures and is a measure of the electron gun emittance plus the effects of any aberrations in the 100 keV beam line.

Chopping the beam increases the measured emittance by a factor which shows no systematic dependence on beam current. This is probably due to the sensitivity of emittance on tuning the second RF deflection cavity for exact cancellation of the transverse momentum imparted to the beam by the first cavity. The chopped beam emittance is lowest (3π mm•mrad) for the beam current (300 μA) for which we have the most experience in tuning, so we expect the emittance at other currents to decrease with more operational experience. In any event, the measured chopped beam emittance was below the 5π mm•mrad design value at all beam currents but one.

The magnetic shielding around the electron gun and the 100 keV beam line was designed to reduce stray magnetic fields to a negligible level on the beam axis. The effectiveness of the shielding was tested by looking for deflection of the 100 keV beam when end magnet E1 was energized. No deflection was observed, which indicates correct performance of the shielding.

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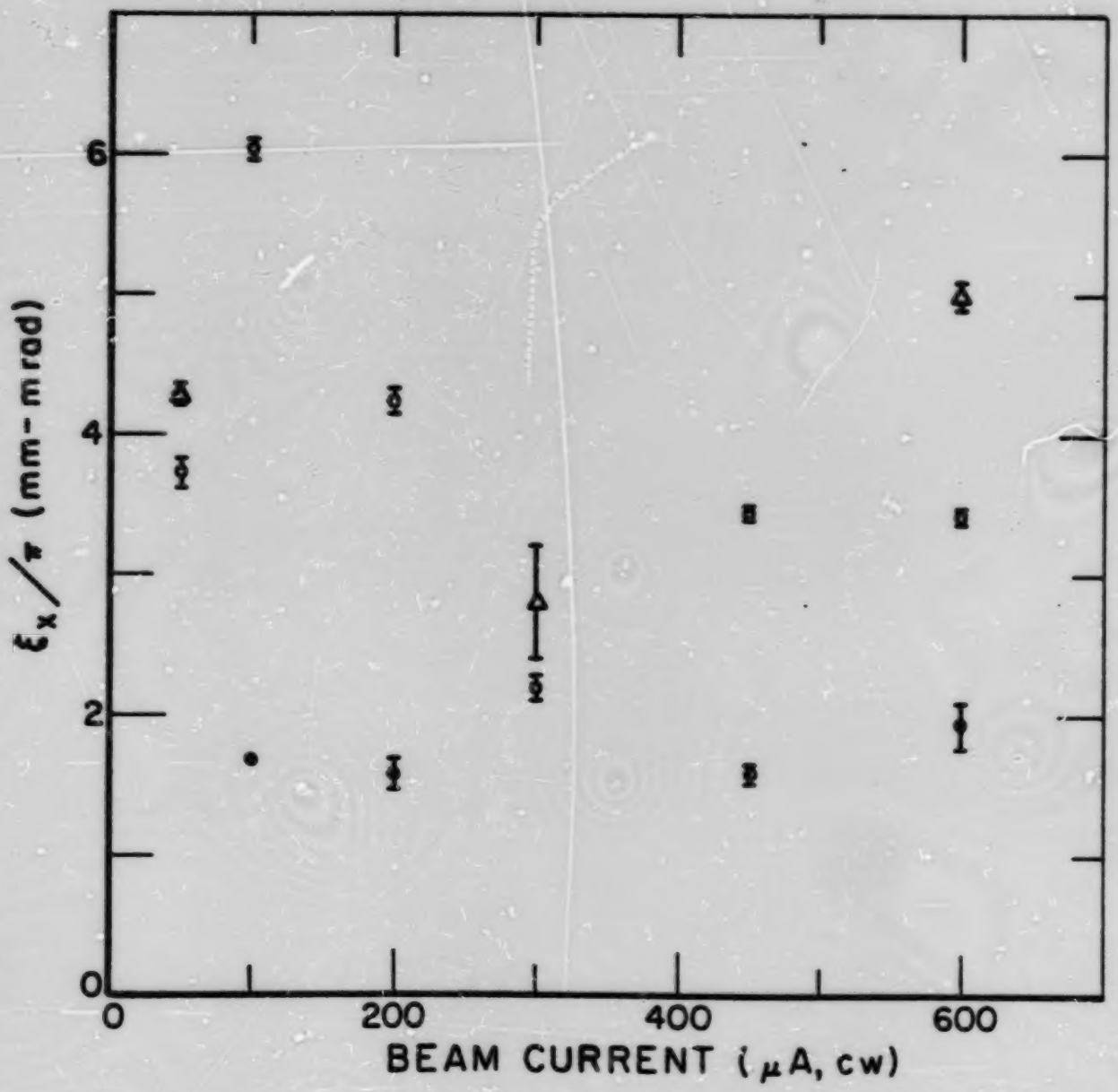

Figure 2 100 keV transverse beam emittance. Dots represent results of measurements on dc beam. Open circles represent chopped beam. Triangles represent chopped and bunched beam. Error bars denote statistical spread in repeated measurements.

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3. 5 MeV Beam Line Phase I

Phase I of the 5 MeV beam transport line will be used for performance tests of the injector linac. As shown in figure 3, it consists of a straight section for measuring the transverse emittance of the 5 MeV beam and a 45° bend for measuring the energy spread. This beam line has been installed, aligned, put under vacuum, and connected to the control system. It is in use for injector linac beam tests.

A design goal for all bending magnets in the 5 MeV transport line is to keep the ratio of sextupole to dipole components below $7 \times 10^{-4} cm^{-2}$. The design calculations for the two identical 45° bending magnets D1 and D2 were consistent with this requirement. Using our recently developed small magnet mapper, described in section E6 of this report, we measured the magnetic field of magnet D1. The measured relative sextupole component is $9 \times 10^{-5} cm^{-2}$ in the uniform field region, and is $4 \times 10^{-4} cm^{-2}$ integrated over the full length of the magnet. The largest contribution is from the field clamps. The measurements also showed excellent agreement with the calculated shape of the fringe field. The measured effective boundary of the fringe field is within 0.5 mm of the calculated location.

Magnets Q1 and Q2 are prototypes of quadrupoles that will be used throughout the RTM. Good quadrupole field purity is required at relatively low field strength. Q1 and Q2 were fabricated of excess 1006 steel from the end magnets to determine if this requirement can be met using this material. Machining was done carefully in the NBS Shop to preserve the annealed condition of the steel as much as possible. Tight dimensional tolerances were achieved in construction. Preliminary field measurements show that the quadrupole purity is approximately 99%, which meets our requirements.

4. 5 MeV Beam Line Phase II

Following performance tests of the injector linac, phase II of the 5 MeV beam line will be constructed to transport 5 MeV beam to the microtron as shown in figure 4. Magnets for this beam line are in the design stage. The 30° bending magnets D4 and D5 are symmetric elements of an achromatic 60° bend and as such must be as close as possible to identical. Their width is tightly constrained by the proximity of D5 to D9. D4 and D5 were originally conceived as having air-cooled coils of solid conductor. Model tests done in the past year indicated that the coil temperature could exceed 100°C with only convective cooling. We have decided to use a different design, shown in figure 5, with hollow, water-cooled conductor. By distributing the extra vertical space throughout the coil as shown, the calculated magnet field uniformity is acceptable, with a sextupole component of $5 \times 10^{-4} cm^{-2}$.

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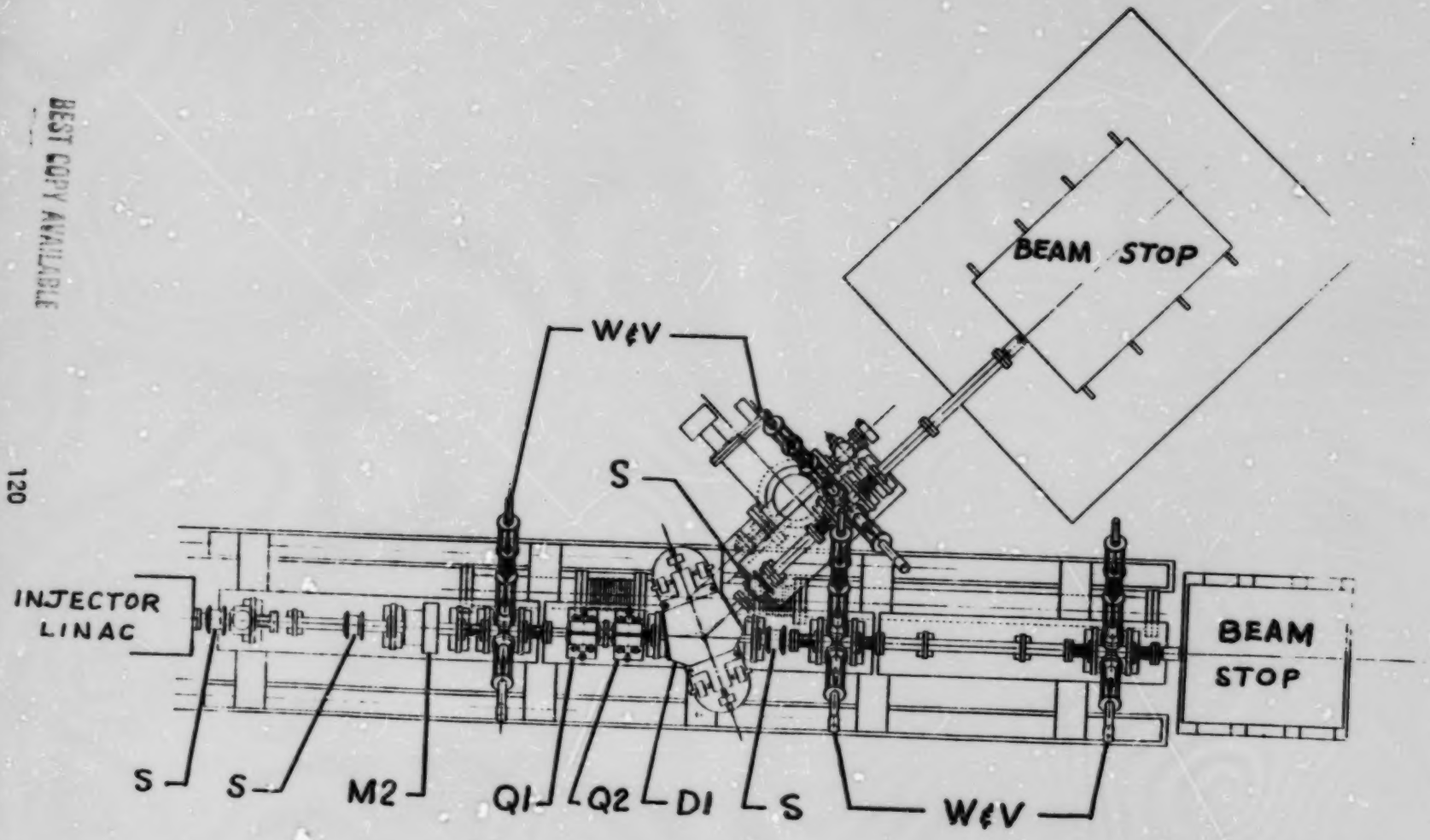

Figure 3 Plan view of Phase I injector transport. The elements labelled "S" are steering dipoles. M2 is an RF beam monitor package. "W & V" denotes wirescanner and viewscreen assemblies.

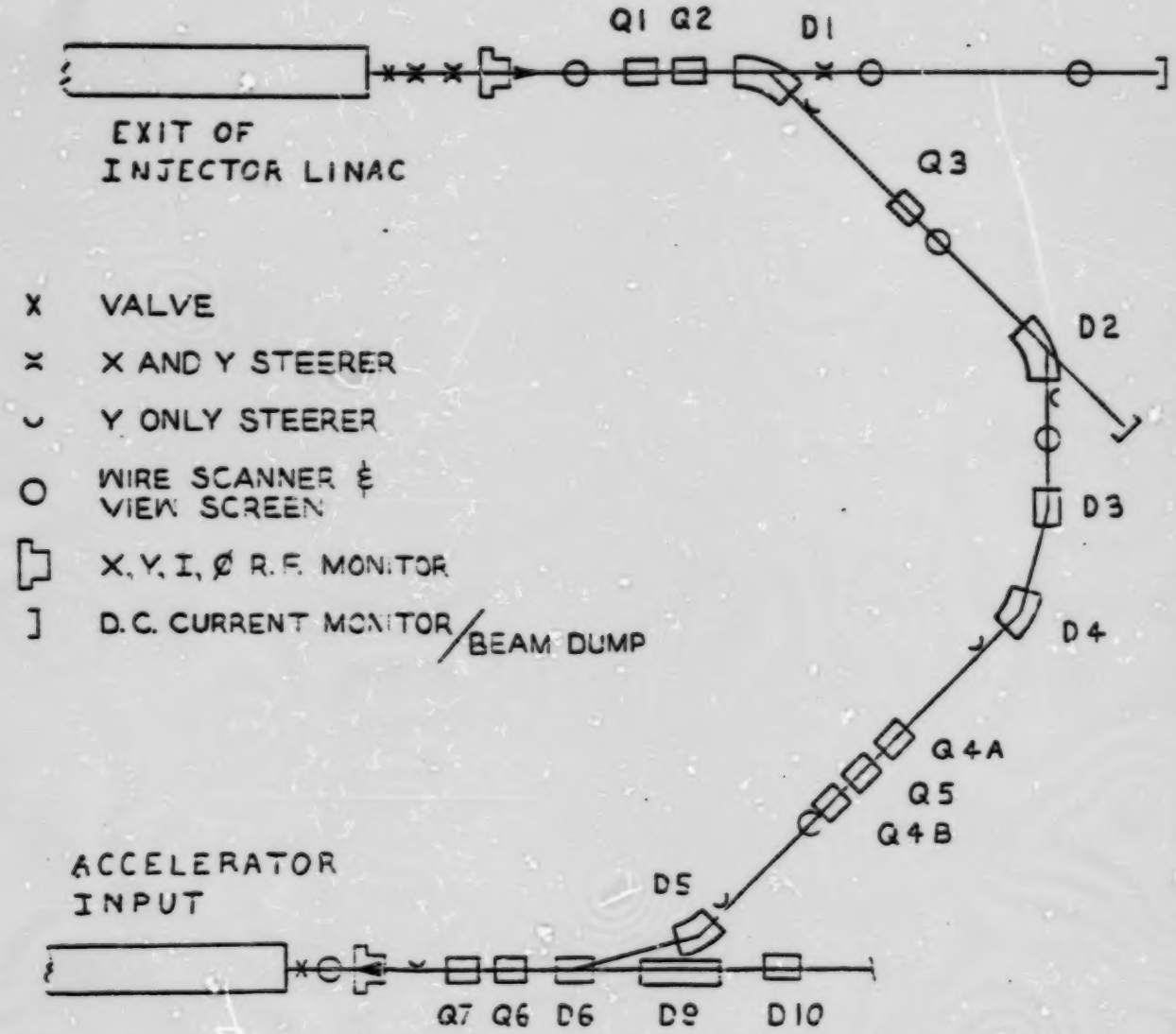

Figure 4 Schematic of injection transport line. This figure is a mirror image of the actual layout.

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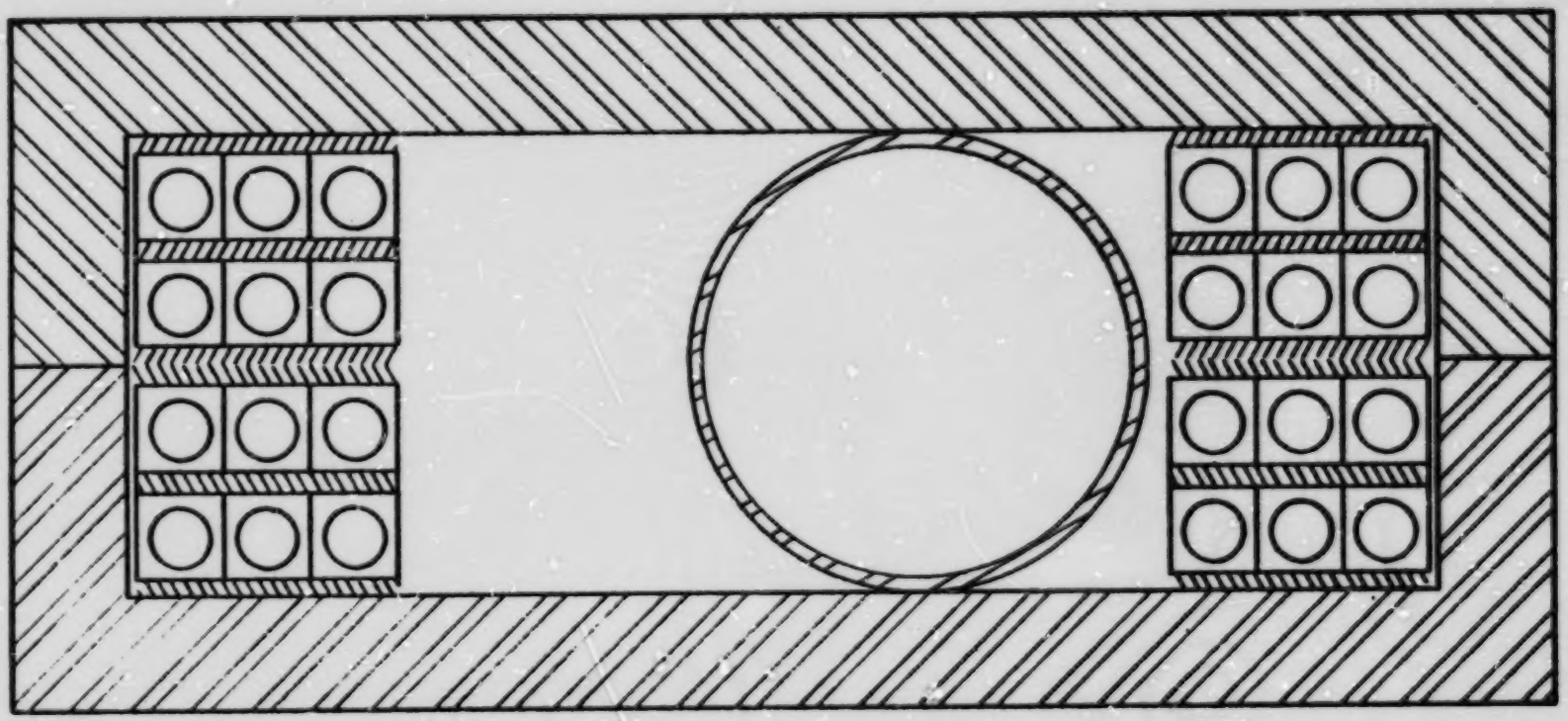

Figure 5 Cross section of the 30° bending magnets for the 5 MeV beam line with vacuum chamber.

B. Microtron

1. Introduction

The microtron consists of a 12 MeV linac, two end magnets, beam lines to recirculate the beam through the linac, and a beam line to extract the beam and measure its properties. In the past year the second of two 4 m long accelerating structures which comprise the 12 MeV linac was completed, and the second end magnet was delivered and installed. Following modification of both end magnets to reduce deflection of the poles during operation, the field of one end magnet was completely mapped and was found to exceed specifications with no trimming. The second end magnet is scheduled for mapping by the end of the fiscal year. The microtron design has been simplified significantly by modifying the design of the injection chicane magnets to include compensation for the effect of the reversing magnets on every orbit. This eliminates the 26 compensation magnets which were to be located on the return lines. Finally, a simplification was made to the extraction line design.

2. End Magnets

The end magnets were designed to generate a uniform field, B, in the operating range 0.8 T to 1.2 T with a field uniformity such that the average fields along each of the first 14 orbits differ by no more than $\pm 2 \times 10^{-4} B$. During the past year the second end magnet was delivered and reassembled on its support stand. Both magnets were accepted from the vendor following successful completion of final coil tests (electric and hydraulic) and dimensional inspection. Meanwhile, the field mapping apparatus was brought into full operation with automatic probe positioning, data taking, and data storage.

Preliminary mapping of the first magnet showed an unexpected and unacceptable field inhomogeneity at the front. We then removed the reversing poles and yokes and observed that as the magnet was energized, the air gap dimension decreased in the vicinity of the inhomogeneity. The problem was that the main yoke was unexpectedly yielding under the magnetic force in the front center of the magnet, and its deflection was being transmitted to the poles by the nonmagnetic shims located between the yoke and the poles. This problem was cured by removing a thickness of material equal to the observed decrease in the air gap symmetrically from the top and bottom nonmagnetic shims. Subsequent measurements confirmed that the gap dimension now remains well within tolerance over the operating field range of 0.8 to 1.2 T.

With the gap constriction problem eliminated in the first end magnet, a complete field map was taken. The results are shown in figure 6 for the uniform field region. The variation in the orbit-averaged field at 1.0 T

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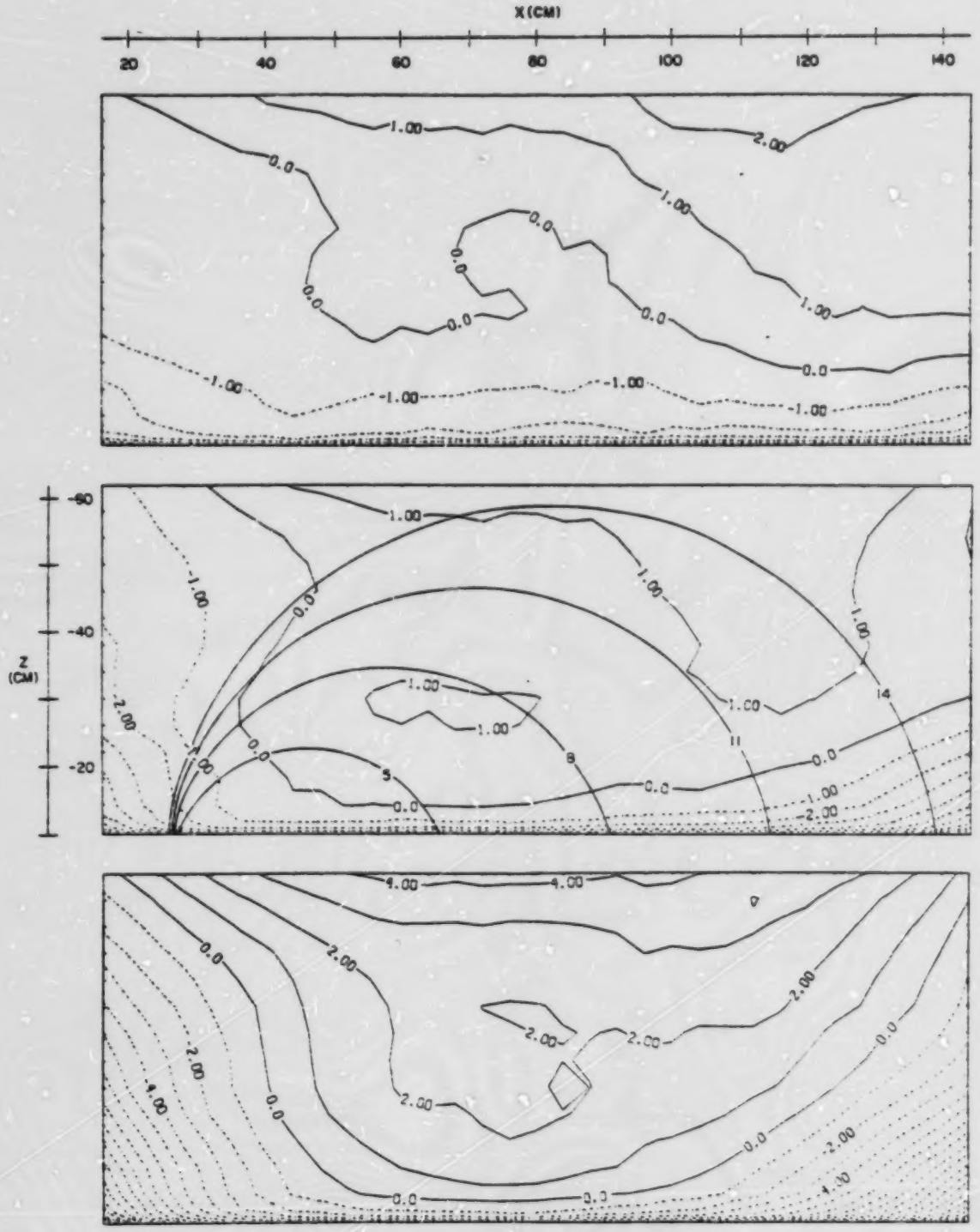

Figure 6 Contour plots of the measured quantity $(\Delta B/B_0)\times 10^4$ on the magnetic midplane in the air gap. From top to bottom, B_0 is 0.8, 1.0, and 1.2T. Negative contours are shown as broken lines. The field measurements were taken on a 4x4 cm grid for z < -12 cm and a Δz = 1 cm, Δx = 4 cm grid for z > -12 cm. On the 1 T field plot, four of the electron orbits are shown.

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is $\pm 4 \times 10^{-5}$, a factor of five more uniform than required. At 0.8 T, the uniformity is even better, and at 1.2 T, the uniformity still exceeds the requirement by a factor of two. The measured fringe field shape is indistinguishable from the design calculations and is virtually identical for every orbit.

The second end magnet has also been modified so that the gap dimension is within tolerance over the operating field range. It is scheduled for mapping in September 1985 and we expect the results to be as good as for the first magnet.

Three dc power supplies will be used to power the end magnets in operation. A 1500 A, 250 kW supply with 10^{-5} current regulation will power the main coils of both end magnets in series. A small trim supply will power auxiliary windings on both magnets in series with opposed polarities to cancel residual field differences between the magnets. A dual-channel, 300 A supply with 10^{-4} current regulation will power the active field clamp coils of the two magnets independently.

The main supply and both channels of the 300 A supply have passed preliminary acceptance tests following delivery. For these tests the supplies were operated into resistive loads at full power. The current regulation, stability, and ripple were within specifications. Both supplies were then used to power the end magnets individually and performed satisfactorily with the exception that one channel of the 300 A supply has gone out of its stability tolerance. Following repair of the dual channel supply and mapping of the second magnet, the supplies will be connected to both magnets and final acceptance tests will be performed. The field difference between magnets will then be measured, and an appropriately rated, commercially available trim supply will be purchased.

3. Microtron Design

In the microtron, every return orbit 2-14 is translated toward the inside of the microtron by the reversing magnets D8 and D7. The translation must be compensated to prevent the returning beam from entering the accelerator off-axis. In the original design, two compensating magnets were used on each return line 2-14, a total of 26 magnets. In the past year we have decided to include the compensation function in magnets D9 and D10 in the injection chicane. This eliminates the 26 individual compensating magnets and simplifies the microtron design.

The design of magnet D9 has been modified as shown in figure 7 to provide compensation for the reversing magnets. The solid-conductor coil of D9 will be powered in series with the coil of D6, with the current in these coils adjusted for correct injection of 5 MeV beam by D6. The water-cooled coil in D9 will be powered in series with the coil in D10 to

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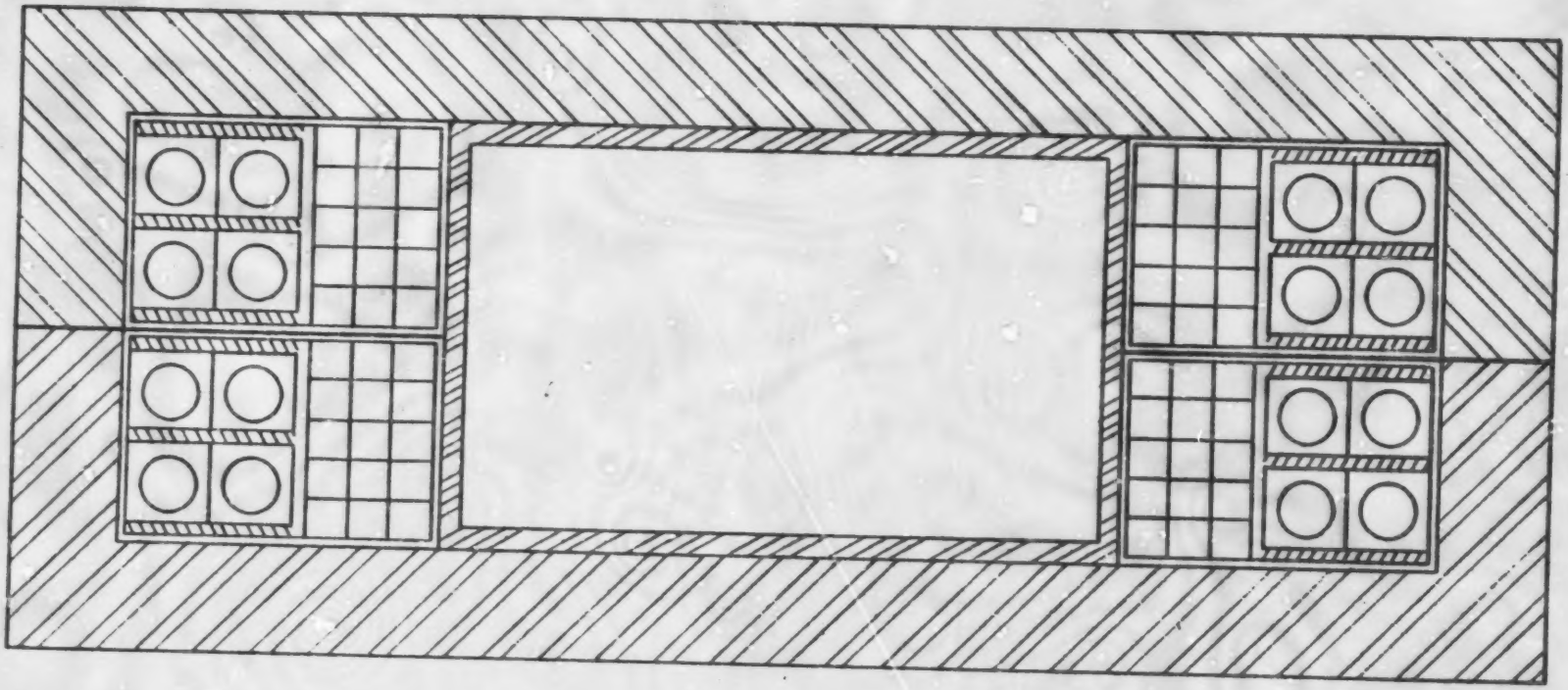

Figure 7 Cross section of magnet D9 with vacuum chamber.

translate the orbits toward the outside of the microtron. The current in these coils will be adjusted to put the second (29 MeV) orbit on the linac axis after traversing D8 and D7. This magnet geometry will then return all higher energy orbits to the linac axis without further adjustment (except minor steering correcting). The arrangement of series coils was chosen because, (for example) if three independent power supplies were used for D6, D9, and D10, the current stability requirement would be at least an order of magnitude more stringent.

We have performed ray-tracing calculations to verify that longitudinal phase space growth in the revised microtron design is acceptable. In the course of performing these calculations, we discovered that the treatment of radial forces in the accelerator section by the microtron ray-tracing program "PTRACE" is quite poor under some conditions. This inaccuracy has no effect on the longitudinal phase space, but affects the transverse focussing significantly at low energies. We are in the process of replacing the accelerator section transverse force algorithm in PTRACE with the corresponding algorithm from PARMELA.

4. Extraction Beam Line

At this time last year it was planned to transport the RTM beam through the linac tunnel and into the adjacent measurement room (MR1) for nuclear physics research immediately upon completion of this project. In the meantime, this plan has been deferred. Consequently, we have been able to make a slight simplification to the extraction beam line design which was presented in last year's report. For energy analysis, the extracted beam will now be deflected 45° by bending magnet D14, as shown in figure 8. A wirescanner located at the focus of D14 will be used to measure the beam energy spread, and a beam dump will be located approximately 1 m past the wirescanner.

C. RF System and Structures

1. Introduction

In FY 1985 most of the RF system has been completed and installed at NBS. Major accomplishments are: installation and commissioning of the 65 kV dc power supply, klystron, and crowbar at NBS; installation, alignment and commissioning of the 5 MeV injector linac at NBS; interfacing and testing of the computer controls for the RF system; and completion of construction of the 12 MeV linac.

2. RF Power System

The RF power system consists of a 65 kVDC power supply, a 450 kW CW klystron, a crowbar unit, and an RF circulator to protect the klystron

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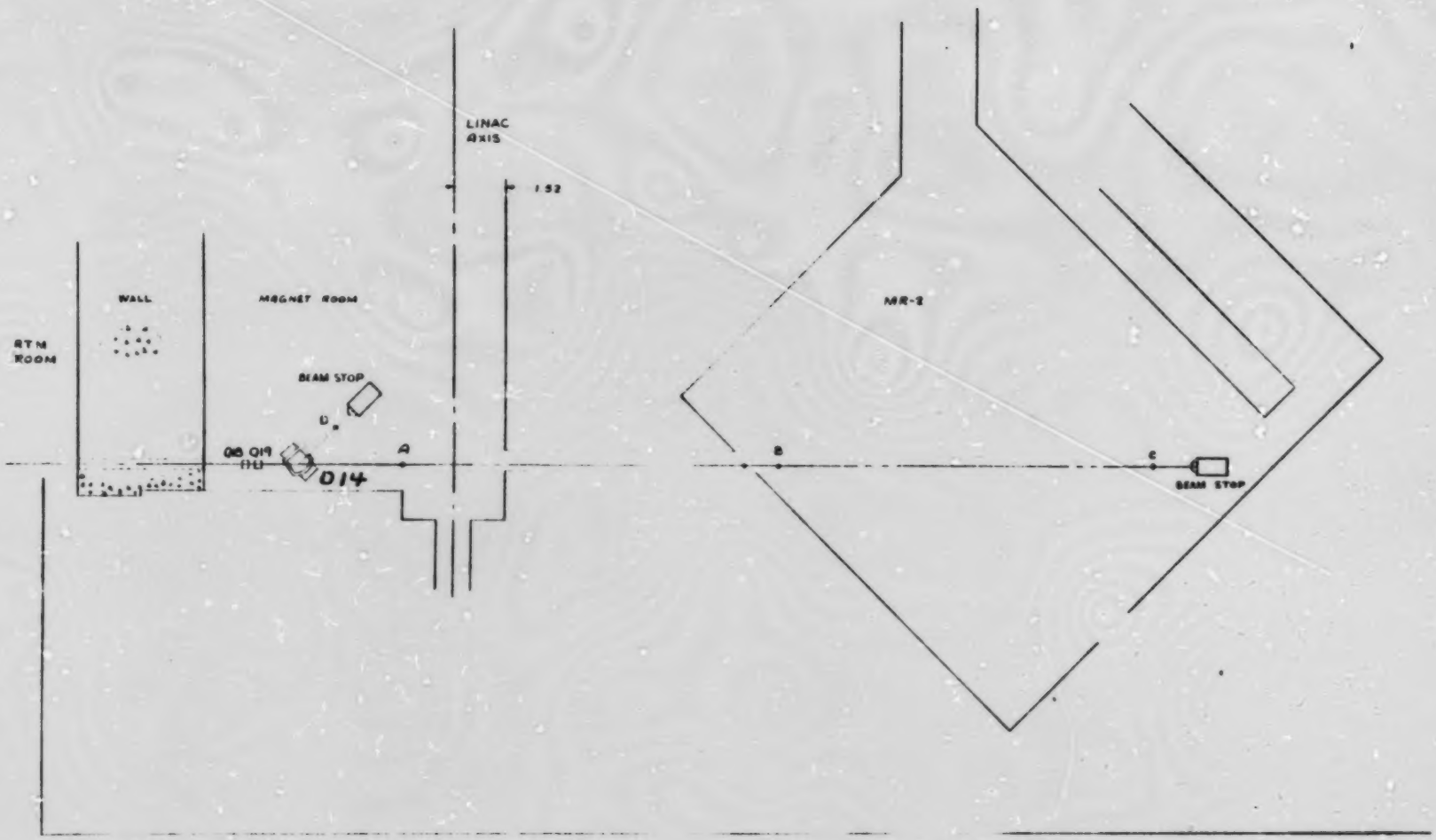

Figure 8 Extension of the extraction beam line from the RTM room, through the magnet room and into measurement room 2. Wire scanners at location A, B, and C constitute the emittance measuring range. Dipole magnet D14 and a wire scanner at location D perform energy analysis in order to determine the beam energy spectrum.

from reflected power. This system has been in operation at Los Alamos since 1983. At NBS, a second power supply was installed in 1981 and a second klystron was delivered in 1982. A crowbar unit for the NBS system was developed at Los Alamos. During FY 1985 the NBS system was brought into operation: the power supply was commissioned; the klystron was installed and tested; and the crowbar and circulator were received from Los Alamos, installed, and tested.

The variable transformer of the NBS power supply was returned to the vendor in October 1984 after the "identical" unit at Los Alamos self-destructed during a crowbar firing because of unrestrained coils. After examining the transformer, the vendor decided it differed from the Los Alamos unit and required no modification. It was returned to NBS in December 1984 and reinstalled. Following approximately one month of operation, the NBS transformer also failed. Currently, we are installing the Los Alamos transformer at NBS while the vendor rebuilds the NBS unit.

Bringing the NBS power supply into operation required a large effort. The vacuum circuit breaker on the 13 kVAC input line did not work initially and required alignment. The wrong control voltage was present in the power supply because the wrong voltage transformer had been installed. There was no regulation of the output voltage. There was no interlock to prevent operation in the absence of the DC voltage which is required to trip the vacuum breaker, a fault which could destroy the klystron. The vendor has been very helpful in resolving these problems.

The power supply has been operated at full output voltage with no load. An output voltage ripple of 1.6% peak to peak is present at 50 kVDC output voltage under load. This ripple is outside the specified 1% maximum but will not present a problem for injector linac operation: it was demonstrated at Los Alamos that the RF amplitude control system can compensate for ripple of up to 2%. If reduction to 1% is desired, it will be undertaken after beam tests of the injector linac.

At NBS the cables between the power supply and the crowbar unit are about 120 m long. To minimize stored energy in these long cables, the high voltage is carried on the center conductor of two cables in parallel. The crowbar has been tested and performs well, quenching sparks in less than 20 μsec. In some test firings of the crowbar unit, components were damaged so that the fast trigger of the quenching circuit failed to fire in subsequent tests. In all such cases, a slower, backup trigger remained effective and quenched the discharge. Reliability of the crowbar has been improved through redesign.

After the klystron and associated cooling water system were installed at NBS, the klystron was conditioned and tested by operating into a dummy load. In order to stay on schedule in spite of the unanticipated work on

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the crowbar, these tests were restricted to proving klystron performance adequate for injector linac operation. The klystron was conditioned to 60 kVDC (90% maximum) and was tested to 250 kW RF output.

3. Injector Linacs and Controls

In November 1984, RF phase and amplitude stability measurements of the injector linac were taken at Los Alamos. The measured variation in 1 hour or more is as follows:

Capture section phase	<±.1°
Capture section amplitude	<± 1 part in 500
Preaccelerator phase	<±.1°
Preaccelerator amplitude	<± 1 part in 1000

The observed stability is more than adequate to achieve proper operation of the RTM.

In November 1984 the injector linac along with the RF power distribution and control systems (waveguide, phase shifters, power splitters, RF phase and amplitude controls, and accelerator cooling water temperature control system) were shipped from Los Alamos to NBS. The injector linac was installed at NBS and put under vacuum in December 1984. The RF power distribution and control systems were installed at NBS in the period January - June 1985. In the same period, separate cooling water systems for the circulator and waveguide were constructed and installed. In July 1985 the installed RF system was tested for correct operation, and the injector linac was reconditioned to its operating RF power level.

In August the injector linac accelerated an electron beam for the first time. The capture section was powered to 25 kW and accelerated the beam to the expected energy, 1.3 MeV. Before the preaccelerator could be phased properly for acceleration, failure of the klystron power supply variable transformer terminated the beam tests.

4. 12 MeV Linac

The main microtron linac is composed of two four-meter-long side-coupled accelerator tanks. Each tank is made up of five separate brazed copper sections that are bolted together with special RF and vacuum joints. These two linac tanks have a total of 126 accelerating cells and are designed to support an accelerating gradient of 1.5 MeV/m and to provide an electron energy gain of 12 MeV per pass. Each tank has its own temperature/resonance control loop and independent RF phase and amplitude

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control. Each tank requires a power feed of 108 kW to maintain the design accelerating gradient plus the power transferred to the beam. Thus at full beam power (100 kW, of which 95 kW is added in the microtron stage), the two tanks together are driven with 310 kW of CW RF power.

The final braze in the fabrication of the main linac was completed in early July. Both tanks were then assembled and tuned. The linac is now complete, including assembly and testing of the plumbing, temperature control, and vacuum systems. The magnetic shields have been fitted, and the residual magnetic field on axis was measured at less than 35 mgauss. The linac will be shipped from Los Alamos to NBS where it will be installed and power-tested.

D. Beam Line Instrumentation

During FY 1985, beam line instrumentation for the 5 MeV injector was developed, constructed, and installed. This instrumentation consists of wirescanners, viewscreens, beam stops, and RF phase, position and current monitors.

Five wirescanners have been constructed and installed in the injector system. These scanners will be able to measure beam size and position with both CW and pulsed beams. Three wirescanners were used earlier to measure the 100 keV injector emittance and achieved their design goal position resolution of 0.05 mm. New amplifiers for the wirescanners were also constructed, with remotely switchable gain and CW/pulse modes. Ten wirescanners are now under construction for the next phase of the project.

Our wirescanner design has attracted a lot of outside interest. We have built and delivered two wirescanners to the Accelerator Laboratory of the University of Saskatchewan and to the MIT-Bates Linac. Two additional wirescanners have been ordered by the Mass Spectroscopy Group at NBS for use with an isotope separator. We provide these devices on a cost-recovery basis with the condition that work of this kind does not delay the RTM schedule.

Five viewscreen mechanisms have been constructed and installed with their associated TV cameras in the injector system. These viewscreens, which are identical to the three already in use on the 100 keV beam line, are suitable for pulsed beam operation only. A computer-operated switching matrix is currently being installed to route the viewscreen current and TV viewscreen images to the control console.

Two beam stops have been constructed and installed on the 5 MeV beam lines to obtain accurate current measurements of the 5 MeV beam. One of the beam stops is designed for up to a 30 MeV, 25 kW beam since it will

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later be used to stop and measure the beam for one- and two-pass RTM operation. Both beam stops are heavily shielded to reduce radiation backgrounds in the RTM room to prevent damage to electronic components.

After the successful completion of tests with a prototype RF beam monitor, as discussed in last year's annual report, two RF beam monitors and their associated electronics were assembled and installed at the entrance and exit of the injector linac. These monitors measure position, current and phase for both CW and pulsed beams. The phase measurement is especially important as it allows the correct phasing of the RF to the accelerators to be determined. Two additional RF monitors are now under construction for use on the main axis of the microtron. A computer-controlled switching matrix is also under construction to switch monitor outputs to the control console display. Additional instrumentation has been developed as part of the accelerator protection interlock chain. These include vacuum monitoring, beam spill (radiation) monitors, and temperature, water, and air pressure interlocks.

E. Control System

1. Introduction

All control system components and subsystems have been installed during the past year that will be needed for essential control and monitoring functions for 5 MeV beam tests. With these and some additional components, most of the basic control system that will be necessary for full accelerator operation is now installed. The primary station, RTM secondary station, and the three magnet tertiary stations were all delivered from Los Alamos in November and subsequently installed. All control system racks necessary for completion of the control system have now been installed in the electrical service cubicle. The present architecture of the control system, slightly modified from that described in last year's report, is shown in figure 9.

2. Primary Station

Permanent installation of the primary station in the control room, as well as the RTM secondary station and magnet tertiary stations, was completed in December. This consisted of modifying the AC wiring of the racks to NBS specifications and making the final AC, rack-to-rack, and primary-to-secondary station interconnections. Additionally, all beam line devices required for 5 MeV operation were connected to the appropriate control outputs or monitoring inputs. During the installation of the primary station a need for remote reset controls at the primary console, for the individual secondary stations, was recognized. The necessary reset controls were designed and installed as part of the primary-to-secondary link cabling. Other devices, such as dual 9-inch monochrome TV moni-

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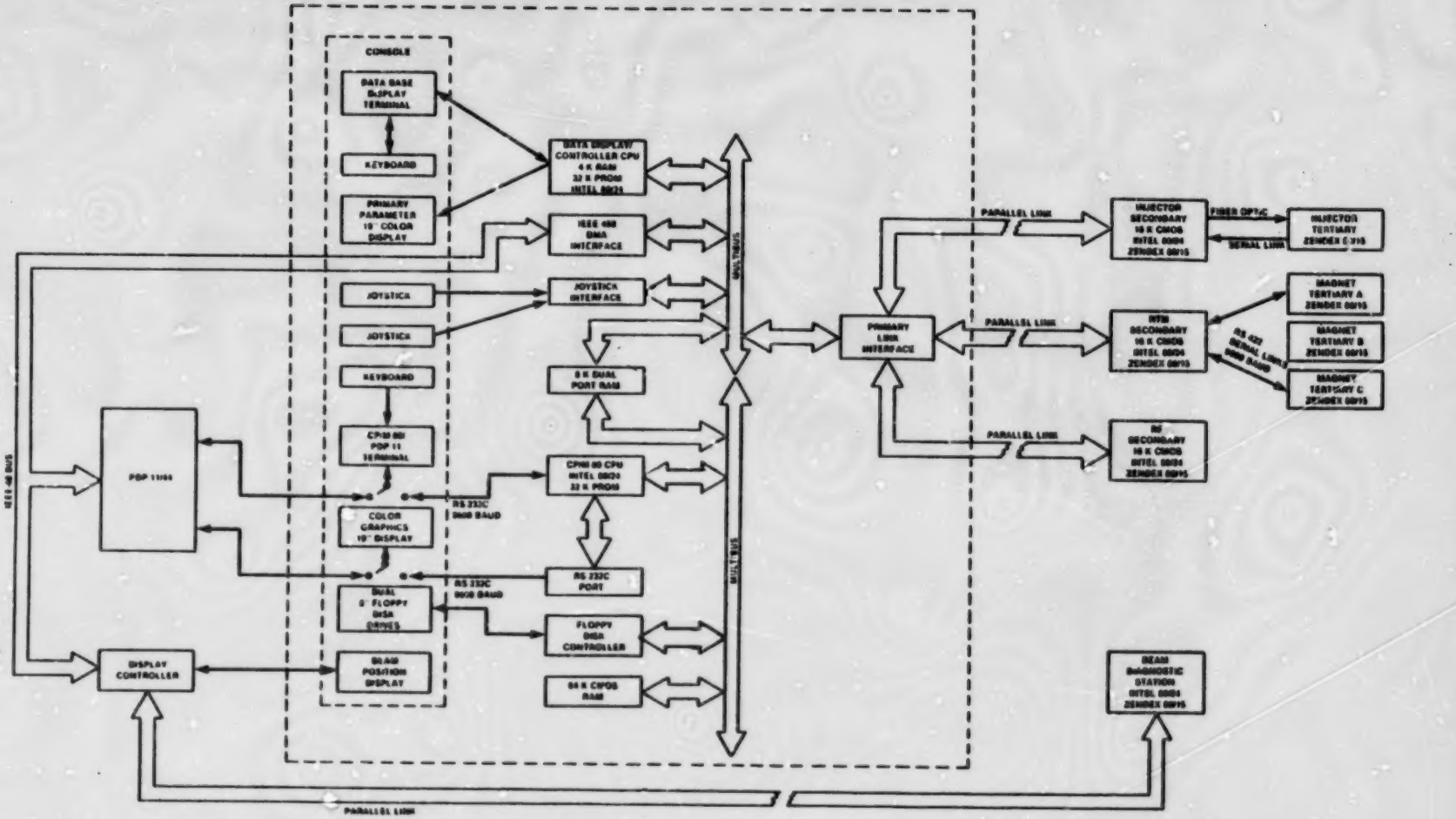

Figure 9 Control System Configuration.

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tors for the viewscreen cameras and dual 350 MHz oscilloscopes for the RF beam position monitors have also been installed in the primary console.

By the end of January, functional testing of the primary control system was completed satisfactoriiy. This included establishing and testing all three primary-to-secondary-station data links and the serial links between the four tertiary stations and their corresponding secondary stations. Control and monitoring of devices from the primary station console through the appropriate secondary and tertiary stations was successfully demonstrated.

Included in the primary station, as delivered, is a second microcomputer system to provide higher level control and monitoring functions than those provided by the main primary station processor. This system is based on an 8085 8-bit single board computer identical to those used throughout the RTM control system. It differs from the design proposed in last year's report, a CP/M-86 system using an Intel 8086 16-bit microprocessor. During software development for the 16-bit system, several design flaws were discovered in the commercial processor board being used that precluded further development along these lines. Fortunately, due to our extensive prior experience with the 8085 processor board, the switch to this board required little additional design effort. The performance of the CP/M-80 system, while lower than that expected from the rejected 16-bit design, has proven to be satisfactory. In fact, the overall performance of the primary station has been increased by removing the CP/M system from the primary control system bus to an independent bus, thereby considerably reducing the primary control system bus traffic. By using a shared, dual-ported, random-access memory for exchange of data between the CP/M and primary control system processors, no reduction in data transfer rate was observed between the two, now independent, processors.

After completion of the functional testing of the entire hierarchical control system (primary, secondary, and tertiary stations) functional testing of the CP/M system was performed. The following CP/M system functions were tested and found to operate satisfactorily:

(1) Saving and restoring control parameter block lists to/from CP/M system floppy disk storage;

(2) Backing up and restoring the complete data base of any one of the three secondary stations to/from CP/M system floppy disk storage;

(3) Automatic control or monitoring of any accelerator parameter;

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(4) The acquisition and plotting of one accelerator parameter as either a function of time or as a function of a second accelerator parameter on a 19-inch high-resolution color monitor.

With the completion of these tests, the basic hierarchical control system is complete and functional for 5 MeV beam tests. Remaining control system tasks to be accomplished in preparation for full machine operation include completion of the link between the primary control system and the PDP-11/44 computer; and design, construction, and installation of the wire-scanner display system.

3. RF System Controls

The klystron control electronics and much of the remaining RF control electronics were delivered to NBS with the capture and preaccelerator structures in November. As a result of the decision to ship the RF secondary station to NBS earlier for chopper/buncher tests, prior to the completion of the RF system design at Los Alamos, considerable unanticipated effort at NBS was required to interface the RF secondary station with the more recently delivered RF control electronics. Because development of the RF control system continued at Los Alamos after shipping the RF secondary station to NBS, numerous bugs were left in the installed but untested RF controls in the RF secondary. Also, new control and monitoring functions were developed that had not been included in the RF secondary station as shipped to NBS. These new functions often conflicted with existing input/output functions in the secondary station that were not present in the temporary system used for RF control tests at Los Alamos after shipment of the RF secondary to NBS. Thus, approximately three man months of additional effort was required after delivery for debugging and retrofitting of the RF secondary to achieve satisfactory operation of the RF control and monitoring system.

4. Interlocks and Vacuum System Controls

During the past year the design, construction, and installation of the permanent replacements for the temporary interlock and vacuum control systems were accomplished. This was a very large effort requiring approximately two man years of work. Careful and conservative design techniques were employed to maximize the reliability of these two critical control subsystems. For example, extra design effort was expended to develop a printed circuit design for the interlock chain plug-in relay cards and a pin and socket card-to-backplane interconnect selected for increased reliability, over the more conventional card edge connector system. Electromechanical relays are used for the interlock chain itself, and noise-immune (HNIL) solid state logic circuits are used to provide latched sensing of interlock faults to the control system. A fault condition in an interlocked device opens the output of the interlock chain, simultaneously

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switching off the electron gun high voltage bias and chopper/ buncher RF drive. Switching off the chopper/buncher RF drive is the fast protect mode, blocking transmission of the electron beam at the chopping aperture in the 100 keV beam line.

The vacuum control and monitoring system was also designed to use electromechanical relays for maximum reliability. A typical vacuum system control and status display panel, and its corresponding manual override panel, is shown in figure 10. A similar set of panels have been constructed for the RTM and extraction line portions of the accelerator. A number of fault condition interlocks are included between the vacuum control and interlock systems. These prevent or interrupt operation of the accelerator when any monitored vacuum point is outside of preset limits or when a valve position is inappropriate for the production of beam. The manual override panel is also interlocked to prevent operation of the accelerator when the vacuum control system is switched to the manual mode of operation. Additional interlocks are included between the RF and vacuum systems to switch off the RF power in the event preset vacuum limits are exceeded in any of the four accelerating structures.

5. Injector Secondary Station Modifications

In the past year, several additional steering and focussing magnets were added to the 100 keV beam line. The interface on the injector secondary station did not accommodate the additional power supplies required. Therefore, a new modular magnet power supply interface was designed, constructed, and installed. The new interface will accommodate additional power supplies if required in the future.

6. Magnet Mapping Systems

Early in FY 1985, the electrical interface between the PDP-11/44 and the end magnet mapper system was completed. This interface included control of the 1500 A end magnet power supply from the PDP-11/44. After completion of testing of the interface, the software for controlling the mapper operation and the logging of data was written and debugged. This system has been successfully used to map the fields in the first end magnet.

Recently, a new small-magnet mapping system was constructed to automate the field mapping of the numerous small magnets required for completion of the project. It consists of a Hall probe and a thermocouple probe mounted on a two-dimensional stage, optical scales to measure probe coordinates, and a microprocessor-based control system to acquire and store data. The mapper control system consists of one of the project's two software development systems, modified by the addition of appropriate

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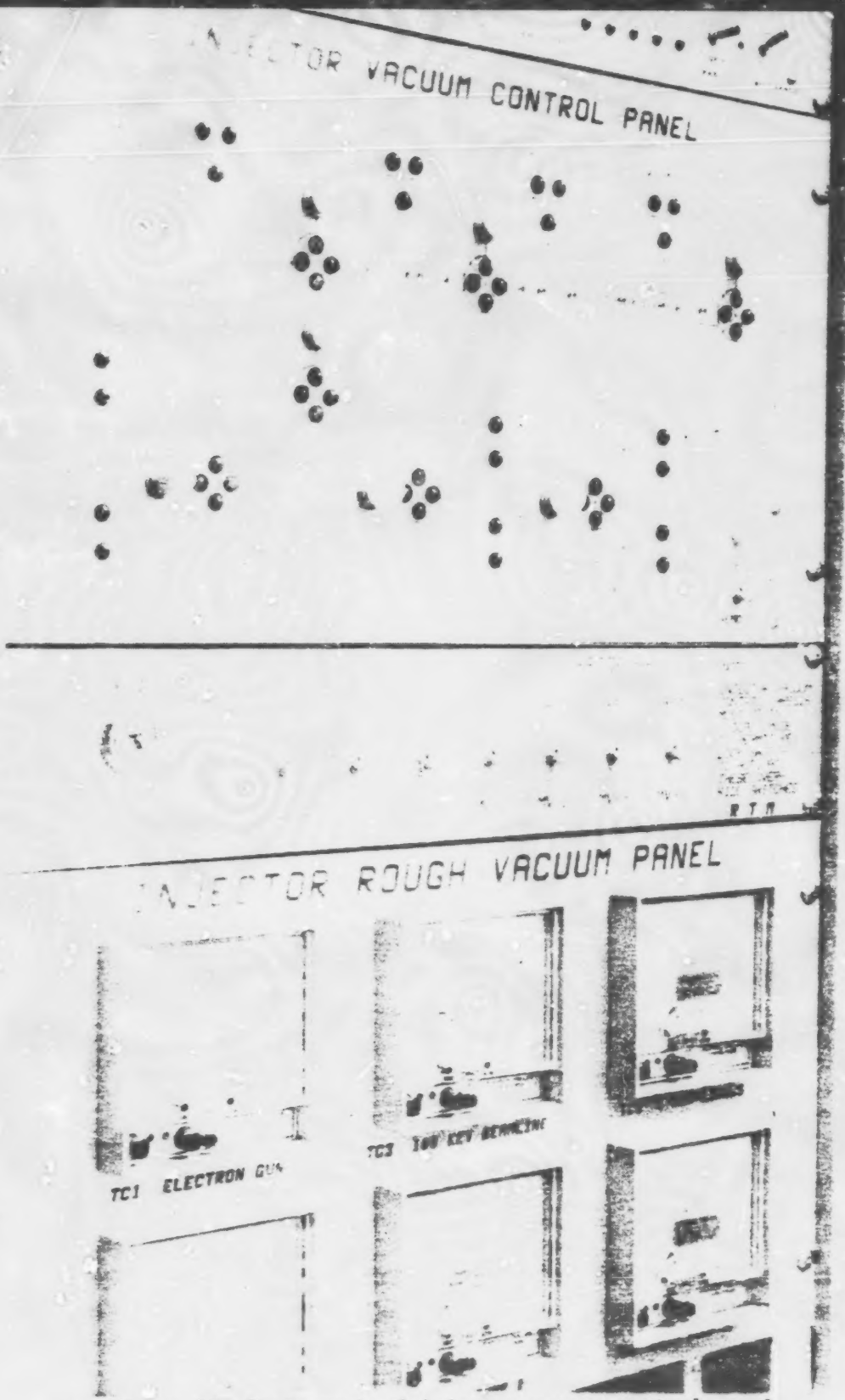

Figure 10 Photograph of injector vacuum control panel.

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hardware and software. Functional testing of the small magnet mapping system has been completed satisfactorily.

7. Maintenance

As the control system approaches completion, the work is shifting away from design, construction, and installation of new control components and software towards maintenance of the present system, many components of which have been in operation for several years, and modifying and improving the operation of existing subsystems and functions. As the complexity of the system continues to increase, the amount of effort necessary to maintain the system is expected to have a proportionate increase.

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LINAC OPERATIONS

Division 535, Radiation Source and Instrumentation Division

The NBS Electron Linac was designed in 1960 with maximum flexibility in order to support a wide variety of program activities of interest to NBS. Major users of the linac in FY 1985 included programs in neutron cross section standards and radiography, high energy electron scattering, photonuclear research, and activation analysis. The last is an activity of the Center for Analytical Chemistry. In addition, a number of outside collaborators and guest workers participated in the above mentioned programs.

The Linac Operations staff has in spite of its relatively small size, achieved a highly commendable operating efficiency as described below. The staff operates and maintains the facility as well as designs, constructs, and installs new equipment to improve operations and extend the capability of the Linac and the beam handling system. The Mechanical Instrumentation Group within the Division provides help by maintaining the integrity of the vacuum and cooling systems of both the Linac and beam handling system as well as designing, constructing, and installing mechanical components. Table I shows the distribution of the total Linac Operations staffing time in operation of the facility for FY 1985 (through July 1985). The facility is staffed from 7:30 am Monday morning and runs for experiments until 6:30 am Saturday. Scheduled maintenance hours have varied throughout the year.

Experiment time on the facility is requested by and allocated to users at scheduling meetings which were held normally every four weeks. Time requested by experimenters did not come up to 100%. Table I shows an unscheduled time of 168 hours. This was a result of several of our users not being able to schedule time due to equipment failure and then taking part in long range planning activities. A new item added is time down due to RTM operation at 320 hours. Table II shows the distribution of time by experiment for the fiscal year.

The unscheduled maintenance of 213.5 hours, through August 1, is broken down and summarized by system in Table III. The small amount of unscheduled maintenance is due in part to having several extra periods during RTM operations to do preventive maintenance.

The RTM is operational to an extent that testing is now necessary, and since the building water cooling system will not permit both the Linac and the RTM to operate simultaneously, their operations must be scheduled jointly. The long range plan is to operate the Linac approximately 1/3 of the time and the RTM 2/3 of the time. With our operational staffing and assuming an 80% efficiency of operation this should give us about 1200 hours of Linac beam time and about 2400 hours of RTM time a year. The

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major Linac user is the Neutron Group, with small amounts of time available for analytical chemistry and others as required.

TABLE I

LINAC OPERATIONS

Month/Year through Aug 85	Scheduled Hours	Actual Hours
Maintenance	312.0	312.0
Unscheduled Maintenance	---	213.5
Beam Time	2502.0	1915.0
Set-Up[1]	98.0	101.5[5]
Experimental Down-Time[2]	---	370.0
RTM[4]	320.0	320.0
Unscheduled Time	168.0	168.0
TOTAL HOURS[3]	3400.0	3400.0

[1] Includes lock-up after scheduled maintenance.

[2] Linac available for operation, but experiment either not ready or breaks down during scheduled run.

[3] Total staffing hours.

[4] During RTM scheduled time preventive maintenance was performed.

[5] This includes 470 hours of training during set up.

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TABLE II

LINAC OPERATIONS

FY 1985
Distribution of Time by Experiment

	[1]Scheduled Beam Hours	Actual Beam Hours	[2]Setup Hours	[3]Unscheduled Maintenance Hours	[4]Experiment Downtime Hours	Total Scheduled Beam%	Total Actual Beam%
ELECTRON SCATTERING	746.0	410.0	17.5	101.0	217.5	28.7	21.4
NEUTRONS	942.0	731.0	41.5	81.0	88.5	36.2	38.2
PHOTONUCLEAR SPECTROMETER	681.0	637.5	23.0	20.5	0.0	26.2	33.3
ACTIVATION ANALYSIS	231.0	136.5	19.5	11.0	64.0	8.9	7.1
	2600.0	1915.0	98.5	213.5	370.0	100	100

[1]Machine time assigned to experiment, includes scheduled setup time of 121.5 hours.

[2]Includes lock-up after scheduled maintenance.

[3]Includes 165.5 hours plant related unscheduled maintenance.

[4]Linac available for operation, but experiment not ready or breaks down during scheduled run.

$$\text{EFFICIENCY} = \frac{1915.0 + 41.0 + 370 + 15.5}{2600.0 - 96.0} \times 100 = 93.5\%$$

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Division 535, Linac Operations (con'd.)

TABLE III

LINAC OPERATIONS

FY 85

LINAC: Total unscheduled maintenance 213.5 hours

System:

Modulators	90.0 hours	42.4%
Injector	51.5 hours	24.1%
RF Drive	8.0 hours	3.7%
Vacuum	7.5 hours	3.5%

No other system or item over 2%.

BHS: Total unscheduled maintenance 39.5 hours.

Balance of total unscheduled maintenance, 17 hours, due to air conditioning and power outage.

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INSTRUMENTATION SERVICES

Division 535, Radiation Source and Instrumentation

Electronic Instrumentation Maintenance and Construction

Provision of electronics instrumentation maintenance and construction services for the experimental programs of the Center for Radiation Research is a continuing responsibility of the Radiation Instrumentation Group in the Division. Instruments designed and constructed during 1985 number about 90 and maintenance has involved about 120 instruments.

Instrumentation Design and Construction

Design and construction of experiment and system control and interlock instrumentation is a continuing and important element of the Radiation Instrumentation Group activities. Examples of this instrumentation this year include: RTM injector, vacuum control and safety interlock system design and construction; RTM magnetic field mapper table probe-positioning system design and installation; neutron spectrometer target ladder programmable oscillator designed and installed; new instrumentation system for the States Regional Calibration Centers designed and constructed and modification of the original systems to new specifications; 300 KV x-ray calibration system computer controller; high-voltage systems safety interlock design and installation; various computer communication links; x-ray calibration source automation; design and construction of a water-graphite micro-calorimetrer measurement system; RTM wire scanner and position-monitor amplifiers; miscellaneous control circuits for shutter, vacuum systems, position monitors etc.

Instrumentation Support for Physics and Chemistry Projects

Consulting and systems instrumentation has been provided to scientists in programs relating to neutron physics, electron physics, surface electron physics, x-ray dosimetry, radiation chemistry, vacuum ultraviolet physics (SURF), analytical chemistry, physical chemistry and photometry. In addition, very considerable support has been provided for RTM projects, one Group technician being assigned full-time to the project with extra assistance on a requirements basis apart from the systems noted above.

The terminal of the 4 MeV electron Van de Graaff was redesigned and rebuilt to accomplish beam pulsing. The beam can now be pulsed repetitively, reliably, with ultra stable and glitch-free pulses from about 5 ns to 5 μs widths, switch selectable. This effort was in support of the radiation chemistry pulse-radiolysis program. Having completely rebuilt the 3 MeV positive ion Van de Graaff last year, the Group has now redesigned and constructed new and much more reliable circuits to replace the

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original designs thus contributing to much greater operating reliability and the achievement of record proton output currents. High voltage pulsed louse drivers have been designed and installed in the STEM project and a very high voltage, bipolar pulse (±3 KV) driver has been designed and installed as a Pockels cell driver. Both projects were for the Electron Physics Group. In addition our Instrumentation Group has designed and installed channel-plate multiplier amplifiers and high-voltage isolators and analog signal-processing circuits for surface magnetic polarization measurements [noted elsewhere]. Design and construction have started on a wire-chamber electron detector for electron scattering spectroscopy. Design of this detector was made possible only by the use of the computer-aided design facilities in the Group laboratories. Printed circuit boards for the wires have been made and spacer frames manufactured. This chamber will be completed in FY '8C.

The Group continues to operate and maintain the HP 9845-based computer-aided design (CAD) system available to all NBS personnel. In addition, the Group has its own HP 9836-based system (newer and much faster). Both systems have been fully utilized with a continuous wait in line for the Group system. Without a CAD facility, effective Group operations would be impossible; manual layout of current printed circuit-boards would be much too time consuming. In addition, all Group technical drawings, layouts, presentation overheads etc. are CAD made. Additional CAD facilities are urgently needed together with software development systems, hardware simulation systems and electronic design support. A new software development system is on order but requirements for the other facilities remain.

Much new equipment is urgently required if the Group is to maintain its competence and effectiveness in providing service to the Center and NBS. In addition to the CAD facilities above some of the Group needs include a DC-22 GHz frequency synthesizer, another Tektronix 7000 series oscilloscope, a fast logic timing analyzer, several MS/DOS- and Unix-based microcomputers and a considerable amount of smaller general purpose, NIM and CAMAC equipment.

Consultation by the Group expert staff continues to be important - not only to CRR but to other Centers in NBS. The cooperative AID program with the Egyptian NIS and NOS continues and further developments await delivery of equipment by the University of Wisconsin to these organizations in Cairo.

A new cooperative program with Harry Diamond Laboratories has been started concerned with high-dose radiation effects on semiconductors. It is anticipated that this will continue and should result in some innovative instrumentation.

Mechanical Instrumentation Services

Mechanical instrumentation services were provided for the Center for Radiation Research in connection with their particle accelerators and their experimental programs. The services provided consisted of design and construction of new equipment and facilities as well as maintenance and modification of existing equipment to improve performance and reliability.

Instrumentation Design and Construction

Design and construction of mechanical devices is an ongoing and important element of the mechanical instrumentation group activities. Examples of these devices built this year are: 45° high precision dipole magnets for RTM; RTM quadrupoles; high precision numerically controlled magnet mapper for the RTM end magnets; 5 MeV and 35 MeV beam dumps for RTM; electron beam target for neutron time of flight experiments. Modified RTM end magnets to achieve required field uniformity and maintenance.

Installation and Maintenance of Facilities

Another major element of our activities is installation and maintenance of major facilities. Examples this year are: installation of both 30 ton RTM end magnets including precision linear motion capability; installation and alignment to ±.002" of the RTM injector linacs; installation of 350 GPM water cooling system into RTM room; installation of the RTM klystron; installation and alignment of the RTM Phase I transport system; installation of RTM RF distribution system including circulator; phase shifters and power splitters; rebuilt motor for the 3 MeV Van de Graaff; rebuilt vacuum pumps for SURF and Linac; maintained mechanical and vacuum equipment on linac to allow 93.5% beam efficiency.

The group staff continues to provide consultation service to other groups in CRR and other NBS organizations. The staff is also consulted by people outside NBS who build and operate accelerators worldwide.

A new CAD/CAM workstation has been installed and made operational. In order to fully realize the potential of this technology several new workstations will be needed in the future.

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RADIATION INSTRUMENTATION STANDARDS

Division 535, Radiation Source and Instrumentation

The Division provides national leadership in the standardization of nuclear instrumentation. The standards work falls into three categories as follows: (a) National Voluntary Standards - The Division plays an active role in the development and processing of Standards of the Institute of Electrical and Electronic Engineers (IEEE) and the American National Standards Institute (ANSI) and participates in the associated policy boards. L. Costrell serves as Chairman of ANSI Committee N42 on Radiation Instruments and as Secretary of the IEEE Nuclear Instruments and Detectors Committee. In these capacities he has processed a considerable number of ANSI and IEEE standards, serves on the ANSI Nuclear Standards Board, and is a member of its Planning Committee.

(b) NIM Committee Standards - This involves development and maintenance of instrument standards, in cooperation with the National Laboratories, primarily for use in nuclear applications. NBS has the management responsibility for this work, with L. Costrell serving as Chairman of the NIM Committee. The Nuclear Instrumentation Module (NIM) system has been adopted nearly universally in the U.S. and is a continuous coordination requirement involving contact with numerous laboratories and manufacturers. Similar management, direction and maintenance are provided in the U.S. with regard to the international CAMAC (Computer Automated Measurement and Control) system that is utilized in the National Laboratories and in a large number of other laboratories and installations throughout the world. A third system for which the Division has similar responsibility is the FASTBUS high speed modular data acquisition system for high energy physics and other applications. The FASTBUS development has been a major effort and is well underway, with commercial equipment available and prototype systems in operation or in preparation in several laboratories in the U.S., Europe, and Japan.

The preparation of reports for the above systems involves a number of individuals and laboratories. Coordination and processing, as well as writing of some sections, is handled by the National Bureau of Standards. The documents are usually issued as Reports of the Department of Energy and then processed as Standards of the Institute of Electrical and Electronics Engineers (IEEE), the American National Standards Institute (ANSI), and the International Electrotechnical Commission (IEC).

The Nuclear Instrument Module (NIM) system[1,2] has had a phenomenal acceptance in laboratories and industry throughout the world. There is a continuous coordination requirement involving contact with numerous laboratories and manufacturers and the resolution of questions that arise. In order to allow and encourage exploitation of technological development

without impairing compatibility and interchangeability, continued vigilance and direction is essential and is provided. The shift from discrete components to integrated circuits and the increasing use of computers and microprocessors necessitates continued accommodation to those devices. Work is proceeding on updating the NIM standard in the light of developments and practice. Also, the division continues to provide information regarding the CAMAC standards.[3]

The FASTBUS standard has been issued as a Department of Energy Report[4] and has also been approved as a standard of the Institute of Electrical and Electronics Engineers (IEEE) and the American National Standards Institute (ANSI)[5] with publication expected in late 1985 or early 1986. Processing as an international standard of the IEC is also progressing with the draft for balloting purposes already submitted.

The NIM and CAMAC standard instrumentation projects have resulted in a savings of at least 1.9 billion 1982 dollars according to a study conducted for the Department of Energy by a firm of economics consultants.[6] The study report states that the 1.9 billion dollars is considered to be a minimum figure conservatively arrived at on the basis of available data. 1.7 billion dollars is attributed to the NIM system initiated by the

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[1] "Standard Nuclear Instrument Modules," AEC (now DOE) Report TID-20893 (Rev 4), July 1974 (currently under revision).

[2] "Standard NIM Digital Bus (NIM/GPIB)," Department of Energy Report DOE/ER-0173, August 1983.

[3] CAMAC Instrumentation and Interface Standards, IEEE Publication SH08482, Library of Congress Catalog No. 8185060 (ANSI/IEEE Stds 533, 595, 596, 675, 683, 726, 758).

[4] "FASTBUS Modular High Speed Data Acquisition and Control System," DOE Report DOE/ER-0189, December 1983.

[5] "FASTBUS Modular High Speed Data Acquisition and Control System," ANSI/IEEE Std 960-1984.

[6] "Benefit Analysis of Selected Accomplishments of DOE's Office of Health and Environmental Research," Final Report RR-166, November 29, 1982, Ecosometrics, Inc. (M. Lago, M.J. Ramsdell, S.F. Knapp, S.I. Siddique, Bethesda, MD.

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Center for Radiation Research[7] and the balance of 200 million dollars to the CAMAC instrumentation system developed by the ESONE Committee of European Laboratories with the active collaboration of the U.S. NIM Committee and the CRR. The report adds: "The benefits were estimated only if they could be documented from the literature or telephone contacts. There are a number of other direct and indirect benefits associated with the use of CAMAC and NIM interfaces which were not considered in this analysis because no measureable data were available." The total worldwide savings can be reasonably projected to be double the U.S savings.

(c) International Electrotechnical Commission - L. Costrell serves as Technical Advisor to the U.S. National Committee of the IEC for IEC Committee TC45 on Nuclear Instruments. He serves as Chief U.S. Delegate to TC45, as Chairman of the Working Group on Detectors and as a member of the working groups on Interchangeability and on Terminology. Numerous IEC draft documents were prepared and reviewed resulting in a number that were published and others that are to be published. These include documents that are technically identical to the NIM and CAMAC standards.[1,2,3] Similarly, the FASTBUS document being processed as an international standard is to be technically identical to ANSI/IEEE Std 960-1984.[5]

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[7] "Standard Modules for Nuclear Instrumentation," NBS Report 8137, December 5, 1963, L. Costrell.

INVITED TALKS

Division 535, Radiation Source and Instrumentation

Penner, S., "Progress Report on the NBS/Los Alamos Racetrack Microtron", Accelerator and Fusion Research Division, Lawrence Berkeley Laboratory, Berkeley, CA, April 12, 1985.

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PUBLICATIONS

Division 535, Radiation Source and Instrumentation

Ayres, R.L., Martin, E.R., Trout, R.E., Wilson, B.L., and Yoder, N.R., NBS/LANL Racetrack Microtron Control System, 1985 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-32, October 1985.

Dawson, W.K., Costrell, L., Ikeda, H., Ponting, P.J., and Walz, H.V., FASTBUS for the Particle Accelerator Laboratories, 1985 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-32, October 1985.

Debenham, P.H., Lindstrom, E.R., and Mohr, D.L., End Magnets for the NBS-Los Alamos Racetrack Microtron, 1985 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-32, October 1985.

Lawson, J.D., and Penner, S., Note on the Lawson-Penner Limit, IEEE Journal of Quantum Electronics, Vol. QE-21, No. 2, February 1985.

Penner, S., Ayres, R.L., Cutler, R.I., Debenham, P.H., Lindstrom, E.R., Mohr, D.L., Rose, J.E., Unterweger, M.P., Wilson, M.A.D., Biddle, R., Martin, E.R., Stovall, J.E., Tallerico, P.J., Wilkerson, L., and Young, L.M., Progress Report on the NBS/Los Alamos RTM, 1985 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-32, October 1985.

Wilson, M.A., Cutler, R.I., Mohr, D.L., Penner, S., and Young, L.M., Performance of the 100 keV Chopper/Buncher System of the NBS-Los Alamos RTM Injector, 1985 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-32, October 1985.

Young, L.M., and Cutler, R.I., Performance of RF Beam Monitor on the NBS-Los Alamos Racetrack Microtron, 1985 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-32, October 1985.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 535, Radiation Source and Instrumentation

Robert L. Ayres

Member, ANSI Technical Committee N42.2 on Procedural Standards for Calibration of Detectors for Radioactive Materials

Member, CRR Word Processing Task Force

Member, IEEE P1014/VMEbus Standard Committee

Member, NBS RIF Assignment Panel

Member, Science and Technical Pool, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC)

Member, NBS Storeroom Committee for ADP

U.S. Representative, Life Sciences Working Group of the International Committee for Radionuclide Metrology

Louis Costrell

Chairman, ANSI Technical Committee N42, Nuclear Instruments

Chairman, IEC/TC45 Working Group-9 on Radiation Detectors

Chairman, DoE National Instrumentation Methods (NIM) Committee

Chief U.S. Delegate, International Electrotechnical Commission (IEC), Technical Committee on Nuclear Instruments (IEC/TC45)

Member, ANSI Technical Committee N41, Controls, Instrumentation, and Electrical Systems for Nuclear Power Generating Stations

Member, IEC/TC45 Working Group-1 on Classification and Terminology

Member, IEC/TC45 Working Group-3 on Interchangeability

Member, 1985 Particle Accelerator Conference Organizing Committee

Member, U.S. National Committee of International Electrotechnical Commission (IEC)

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Division 535, Technical and Professional Committee Participation and Leadership (cont'd.)

Secretary, Institute of Electrical and Electronics Engineers Nuclear Instruments and Detectors Committee of IEEE Nuclear and Plasma Sciences Society (IEEE/NPSS)

Technical Advisor, U.S. National Committee of IEC

Philip H. Debenham

Member, DoE POISSON Working Group

Member, DoE Small Business Innovation Research Review Panel

Member, 1985 Particle Accelerator Conference Program Committee

Participant, DoD Emerging Technologies Workshop

Samuel Penner

Chairman, 1987 Particle Accelerator Conference

Member, DoE Aladdin Upgrade Review Committee

Member, Organizing Committee for 1986 Heavy Ion Fusion Workshop

Member, 1985 Particle Accelerator Conference Program and Organizing Committees

Member, Review Committee for the "Review of Scientific Instruments"

Julian K. Whittaker

Chairman, NBS Property Review Advisory Board Panel

Member, ASTM Committee D-22 on Methods of Sampling and Analysis of Atmospheres

Member, DoC Industry and Trade Administration, Electronic Instrumentation Technical Advisory Committee

Division 535, Technical and Professional Committee Participation and Leadership (cont'd.)

Neil D. Wilkin

Member, Electronics Storeroom Committee, NBS

Mark A. Wilson

Member, Organizing Committee for Heavy Ion Fusion Workshop

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MAJOR CONSULTING AND ADVISORY SERVICES

Division 535, Radiation Source and Instrumentation

1. R. Ayres serves as a member of the U.S. Pharmacopoeia Convention Advisory Panel to the Subcommittee on Radiopharmaceuticals.

2. S. Penner and M. Wilson continue to provide Accelerator Technology and Assessment and Oversight for DARPA.

3. S. Penner served on JASON panel to evaluate SDIO sponsored FEL programs.

4. J. Whittaker serves as a consultant on instrumentation and instrumentation maintenance and repair to AID for the Egyptian Government Standards Laboratories.

5. J. Whittaker serves as a consultant on electronics instrumentation and instrumentation repair and maintenance to the University of Petroleum and Minerals, Dhahran, Saudi Arabia.

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SPONSORED SEMINARS AND COLLOQUIA

Division 535, Radiation Source and Instrumentation

NBS Nuclear, Radiological, and Accelerator Physics Seminar, "The Design Study for the Advanced Light Source," Richard Sah, Accelerator and Fission Research Division, Lawrence Berkeley Laboratory, Gaithersburg, MD, December 13, 1984.

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TECHNICAL ACTIVITIES

Division 536, Ionizing Radiation

Task No. 15201 - Radiation Standards Dissemination
Task No. 15221 - Neutron Radiation Safety
Task No. 15225 - Neutron Field Standards
Task No. 15226 - Radioactivity Standards
Task No. 15227 - Neutron Measurements and Research
Task No. 15602 - Physical/Technological Property SRM Research
Task No. 15645 - Computerization of Standard Reference Data Bases
Task No. 15231 - Radiation Measurement Standards and Technology for Health and Safety
Task No. 15232 - Radiation Measurement Standards and Technology for Industrial and National Programs

The Ionizing Radiation Division was formed on August 4, 1985 from some of the groups of the former Nuclear Radiation Division and of the Radiation Physics Division. The basic purpose of the organizational change was to consolidate all programs in ionizing radiation measurements, standards, and research in a single division. Nuclear physics research activities in the old Nuclear Radiation Division were transferred to a new Nuclear Physics Group reporting to the CRR Director.

The functions of the new Ionizing Radiation Division are summarized in the following table:

- Provides primary national standards, dosimetry methods, measurement services, and basic data for applications of ionizing radiation (x rays, gamma rays, electrons, neutrons, and radioactivity, etc.) in such areas as:

  - Radiation protection of workers and the general public
  - Radiation therapy and diagnosis
  - Nuclear medicine
  - Radiography
  - Industrial radiation processing
  - Nuclear energy
  - National defense
  - Environmental protection

- Conducts theoretical and experimental research on the fundamental physical and chemical interactions of ionizing radiation with matter to provide the competence for:

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Division 536, Technical Activities (cont'd.)

- Developing improved understanding of the physical stage of the interaction of ionizing radiation with matter.
- Developing an understanding of basic mechanisms involved in radiation-induced chemical transformations and the parameters that influence the yields of short-lived intermediates, final chemical products, and biological effects
- Developing improved methods for radiation measurement, dosimetry, and radiography
- Developing improved primary ionizing radiation standards
- Producing highly accurate standard reference data for ionizing radiation or radioactive materials

- Provides essential standards and measurement support services to the National Measurement Support System for Ionizing Radiation that provides calibrations and measurement quality assurance services to:

  - Medicine
  - Industry
  - States
  - Other Federal Agencies

- Develops and operates well-characterized sources of electrons, photons, and neutrons to provide:

  - Primary radiation standards and fields
  - Well-characterized beams of radiation for research on radiation interactions and for measurement methods development.

To carry out the functions of the Ionizing Radiation Division, the initial group structure shown below has been adopted. As we understand the mission and research program of the Ionizing Radiation Division better, it is quite possible that the group structure will be modified to reflect this understanding.

Ionizing Radiation Division Office (R. S. Caswell)
Office of Radiation Measurement (E. H. Eisennower)
Radiation Theory (M. J. Berger)
Radiation Chemistry & Chemical Dosimetry (M. G. Simic)
Neutron Measurements & Research (O. A. Wasson)
Neutron Dosimetry (J. A. Grundl)
Radioactivity (D. D. Hoppes)
X-ray Physics (J. W. Motz)
Electron & Photon Dosimetry (R. Loevinger).

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Office of Radiation Measurement

The function of the Office of Radiation Measurement is to promote the dissemination to federal, state, and local radiation control programs, and to the medical, industrial, and defense communities, of the measurement standards and technology required for reliable measurement of ionizing radiation. The Office assists the technical organizational components of the Ionizing Radiation Division in monitoring the radiation measurement needs of these national user groups, and in activities undertaken to meet national needs. The latter include methods for improving the consistency of field measurements with the national physical measurement standards. The Office maintains liaison with organizations that conduct measurement-intensive programs in the areas of radiation safety, energy, health, and environmental contamination. Examples are the Nuclear Regulatory Commission, Department of Energy, Food and Drug Administration, Environmental Protection Agency, Health Physics Society, and the Conference of Radiation Control Program Directors. The Office participates in collaborative programs with most of these organizations to satisfy specific measurement quality assurance requirements. Another function of the Office is to provide the chairman for American National Standards Committee N43, concerned with equipment for non-medical applications of ionizing radiation.

Radon (R. Collé & J. M. R. Hutchinson)

The growing concern about exposure of the public to radon and radon progeny throughout the United States has resulted in increased interest in the quality of radon measurements. In response to this concern, the Office has directed its activities toward developing new transfer standards and to maintaining liaison interactions with other radon measurement laboratories. Significant progress was made in the past year.

For the development of new transfer standards, the Office continues to collaborate and conduct laboratory studies with staff members of the Radioactivity Group. These collaborative projects included the successful completion of a radon-in-water standard, ongoing work to develop a flux density standard, and extensive modifications to the radon measurement and test facility.

A final version of the radon-in-water standard was transmitted to the Environmental Protection Agency. This standard consists of a polyethylene-encapsulated radium solution source in a small-volume accumulation chamber, and an ancillary mixing and dispensing system. It generates aqueous solutions of radium-free radon of which multiple aliquots may be dispensed and used as standardized solutions for calibrating radon-in-water assay procedures. In the past year, extensive performance tests were conducted on the standard, detailed operating instructions were

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developed, and the final calibration and certification of the standard was completed. A paper on the development and performance of the standard is in preparation.

The Office continued to provide oversight for the overall project to develop a flux density standard. This project is funded in part by an interagency agreement with the Environmental Protection Agency. A 40-cm diameter prototype was fabricated, and it was loaded with a radium solution after a suitable circulation system and a safe and efficacious loading procedure were developed. Preliminary measurements on the prototype were initiated in February, but had to be terminated because the polyethylene to stainless steel seal proved to be inadequate. The prototype had to be dismantled, decontaminated, and modified to incorporate additional O-ring seals. To save time (and hopefully avoid the need for ever having to decontaminate or reload the prototype more than once again) an entirely different and auxiliary experimental effort was undertaken. The goal was to better understand and characterize the diffusion of radon through polyethylene in a configuration much simpler than the prototype. For this work, a 2-liter "diffusion cell" was fabricated and used to measure the diffusion coefficient, and to estimate the "relaxation time" for the source to reach a steady-state condition (i.e., a constant radon concentration profile in the polyethylene layer, and hence a constant flux density) as well as the relaxation time dependence on polyethylene thickness. These auxiliary measurements with the diffusion cell were recently completed. The results for the diffusion coefficient and other parameters are in good agreement with the initial design estimates. Following the modification and reassembly of the prototype, we are at present conducting further tests with the prototype loaded with just a gaseous radon source. This configuration is very similar to the small diffusion cell studies. A constant radon concentration is flowed through the prototype, and the exhaled radon from the prototype surface is accumulated and continuously monitored to evaluate the constrained flux density. On completion of these tests, it is envisaged that the prototype will be reloaded with a radium solution before the end of the year. In collaboration with a staff member from the Center for Materials Science, who derived a mathematical model for the prototype, the design calculations performed last year were considerably extended to include time-dependent cases for the constrained exhalation rate. This ongoing work on the development of a flux density standard was reported at the annual Health Physics Society meeting in Chicago.

The radon measurement and test facility used for the above studies was completely rebuilt in the past year. The old system was dismantled, and a new all glass and stainless steel sampling and monitoring manifold (separate from the 600-L test chamber) was constructed and extensively tested. It has been fully operational since early Spring. The design of this new system provides much greater range and flexibility in different types of gas sampling and radon monitoring that can be performed.

In addition to these laboratory studies, the Office continues to coordinate the interactions and measurement intercomparison activities between NBS and other radon measurement laboratories, such as the DoE Environmental Measurements Laboratory, the DoE Technical Measurements Center (operated by Bendix in Grand Junction, Colorado), two EPA laboratories at Montgomery and Las Vegas, the U.S. Bureau of Mines Denver Research Center, and national laboratories including Lawrence Berkeley Laboratory, Argonne National Laboratory, Oak Ridge National Laboratory, and Mound Laboratory. The Office also continued to advise and collaborate with personnel in the State of Wisconsin Department of Health on calibration procedures for radon measurements and on the evaluation of a commercially-available radon source. In the past year, plans were made for a collaborative radon flux density measurement intercomparison with the DoE Environmental Measurement Laboratory, Colorado State University, and the EPA Eastern Environmental Radiation Facility; discussions were initiated with the National Academy of Sciences and with other groups on the design of a national indoor radon survey; and additional contacts were made with the Harvard School of Public Health and several international laboratories.

Measurement Theory (R. Collé)

The Office's expertise in the treatment and reporting of measurement uncertainties continues to be very useful to groups both within and external to NBS. In the past year, many individuals and groups have been assisted by the Office. In particular, an Office staff member served on a "panel of experts" for a workshop on error analysis held at the annual symposium of the National Conference of Standards Laboratories. The Office also made substantial contributions to the new sections on measurement assurance, traceability, and the statement of uncertainty for the second edition of the National Council on Radiation Protection and Measurements report on radioactivity measurements procedures (NCRP Report No. 58).

Regional State Laboratories (H. T. Heaton & E. H. Eisenhower)

At present the Office is cooperating with five states in establishing regional calibration laboratories for ionizing radiation. The main radiation sources in these laboratories are a 150-kilovolt x-ray machine, with filtration corresponding to five NBS beams, and ^{137}Cs irradiators with source strengths of 3 curies and 30 millicuries. Beams from these sources are used to calibrate survey instruments at radiation protection levels and x-ray instruments used for diagnostics.

The laboratory in Springfield, Illinois continues to be the only one accredited by the Conference of Radiation Control Program Directors so far. Based on successful participation in a second performance evaluation, their accreditation for both x-ray and gamma-ray calibrations was

renewed in July, 1985. To date they have calibrated instruments for nine other state radiation control programs. This laboratory is considering extension of its services to include calibration of instruments used for monitoring environmental levels of radiation and calibration of pulse-counting instruments.

The laboratory in Seattle, Washington has successfully participated in a performance evaluation for gamma-ray calibrations with the 3-Ci ^{137}Cs source. Revision of the procedures manual is underway and, when that is satisfactorily completed, it is anticipated that the CRCPD will grant accreditation for gamma-ray calibrations with the 3-Ci source. Until accreditation is received for gamma rays, minimal effort will go into developing the x-ray calibration capability. This laboratory is presently performing unaccredited calibrations of survey instruments for the Oregon and Washington radiation control programs.

Due to limited manpower availability, the laboratory in Columbia, South Carolina is not developing as rapidly as expected. The 150-kV x-ray machine is operating, and procedures for its use in calibrations are under development. The 3-Ci ^{137}Cs source has been delivered but the necessary shielding calculations and verifying radiation survey measurements have not yet been completed.

Building modifications for the laboratory in Sacramento, California have been completed and the x-ray machine was installed in August, 1985. A training course in x-ray calibrations was provided by the Office for personnel from the Radiological Health Section, Office of Emergency Services, and Division of Weights and Measures. The laboratory recently received authorization from FEMA to replace the 50-Ci manually-operated source with a new 100-Ci pneumatically-operated ^{137}Cs source together with a new calibration track system.

In Fayetteville, Arkansas, modifications to existing space are nearing completion. This laboratory will be developed with funds provided by Congress in FY 1985. The existing capability to provide calibrations using neutron sources will be expanded to include x-ray, beta-particle, and gamma-ray capability. As a result of this expanded range of calibration services, it is necessary for the Radiation Measurements Committee of the Conference of Radiation Control Program Directors to broaden their accreditation criteria to include all of these sources and services.

Collaboration with personnel from the California Division of Weights and Measures has resulted in the development of new procedures for calibrating the electrometer and picoampere current source used in each state laboratory. A computer code is being developed that will allow the state laboratories to calibrate these instruments on site, using a reference voltage, standard resistor, and standard capacitor.

Measurements of x-ray beam half-value-layers at the Illinois and South Carolina laboratories indicate that the preset machine kilovoltage may not be the actual kilovoltage. Two methods of determining the actual kV are being investigated. The first involves measurement of the half-value-layers using the NBS 150-kV machine under a set of specified conditions. This includes developing computer codes to unfold the energy response of the ion chamber from the measured transmission values and a study of the systematics of various experimental conditions. The second approach is to measure all of the components in the high voltage circuit used to monitor the actual kilovoltage. This is being carried out in collaboration with personnel from the California Division of Weights and Measures.

Committee Activities (H. T. Heaton, R. Colle, & E. H. Eisenhower)

The Office serves on two major interagency committees concerned with environmental radon exposure. The first is the Radon Workgroup of the Interagency Committee on Indoor Air Quality (ICIAR). This group recently completed a report on the status of current federal activities and priorities for radon research in the U.S. It also advised and assisted the ICIAQ parent committee in developing a Comprehensive Indoor Air Quality Research Strategy (published June, 1985). Future activities of the workgroup include a progress report on the development of a national indoor radon assessment plan and the appropriate Federal role in conducting this large-scale project. The second committee is the Science Subpanel on Radon Protection and Health Effects of the Committee on Interagency Radiation Research and Policy Coordination (CIRRPC). The Radon Subpanel was one of the first five working groups formed by the CIRRPC Science Panel. A first report by this subpanel is in preparation. For this report, the Office contributed a draft chapter on the status and quality of radon measurements made in the U.S. and on other measurement considerations.

The Office has also participated in the activities of the CRCPD Committee on Adequate Criteria for Environmental Monitoring and Surveillance Programs. This committee, established last year, completed a draft criteria document. The document was distributed to the state radiation control program directors for review and comment, and is presently undergoing a final revision.

For the past three years, a member of the Office staff has served as the Department of Commerce representative to the Interagency Working Group on Occupational Exposure Guidance. This group, consisting of representatives of 10 government agencies or departments, assisted the Environmental Protection Agency to prepare guidance that will replace the Federal Radiation Council guidance issued in 1960. The new guidance has been approved by all the participating agencies and will be submitted to the Office of the President for publication in the Federal Register in the near future.

After more than 38 years, NBS has relinquished the secretariat of American National Standards Committee N43, Equipment for Non-Medical Radiation Applications. The Committee considered offers of a new secretariat from four candidate organizations, and selected the Health Physics Society. The Office will continue to provide the committee chairman until the summer of 1987, at which time a new chairman will be elected by the committee. In a closely related activity the Office prepared, during the past year, a comprehensive glossary of radiography terms under sponsorship by the Department of Defense.

Personnel Dosimetry (E. H. Eisenhower)

The national quality assurance program for personnel dosimetry operated routinely during the past year under the procedures of the National Voluntary Laboratory Accreditation Program (NVLAP). Forty-seven dosimetry processors have applied for accreditation and 26 of them have been accredited so far. The Nuclear Regulatory Commission is preparing a final rule that would require its licensees to use only accredited processors, and a number of states have taken similar action. Technical support and guidance for this program have been supplied by the Office and the Dosimetry Group. The Office provides the chairmanship of an interagency committee that provides guidance and coordination for this national program.

I. Radiation Theory Group

Bremsstrahlung Cross Section (S. M. Seltzer & M. J. Berger)

Work has been completed on the evaluation and tabulation of this cross section which is a key input for radiation transport and radiological physics calculations. This work includes not only the bremsstrahlung spectrum resulting from the Coulomb interactions of incident electrons with screened atomic nuclei, but also the spectrum resulting from the interaction of electrons with atomic electrons. The bremsstrahlung cross sections were evaluated through the synthesis of results obtained with a variety of analytical and numerical methods. The methods used have been described in a detailed expository paper, to appear shortly in Nuclear Instruments and Methods, which also contains cross section tables for selected elements. This paper also demonstrates, through extensive comparisons that the tabulated cross sections are in good agreement with experimental data. A complete set of bremsstrahlung cross section tabulations has been submitted for publication to Atomic Data and Nuclear Data Tables. This compilation includes the cross sections for electron-atom and electron-electron bremsstrahlung, for all elements with atomic numbers $Z = 1$ to 100 for electron energies between 1 keV and 1000 GeV.

Predictive Algorithm for Photon Cross Sections (M. J. Berger, S. M. Seltzer, & J. H. Hubbell)

In radiological physics and radiation protection work, photon cross sections for scattering and absorption, as well as total attenuation coefficients may be required for an enormous variety of materials, too many to allow convenient tabulation in print media. To overcome this difficulty, a set of computer programs has been developed which can be used to obtain photon cross sections for any material of interest, through the additive combination of cross sections for atomic constituents. The codes take into account the presence of the separate absorption edges for each of the constituents, and also allow either for easy and accurate interpolation to any desired set of photon energies or for output according to a standard photon energy list. To facilitate the rapid and efficient execution of the combination and interpolation algorithms, a cross-section data base was developed for photon energies from 1 keV to 100 GeV and for elements with atomic numbers Z = 1 to 100. Even though the computer programs (in FORTRAN 77) are portable, the implementation of the programs is nevertheless slightly machine dependent. Several code packages have therefore been developed, including batch-submission versions for Univac 100 and IBM 3081 computers, and interactive versions for IBM 3981 and Control Data Cyber 855 computers. The interactive versions allow the user to enter the composition of the material of interest in terms of chemical formulas at a terminal, and provide neatly organized cross section tables on the screen or attached printer.

X-Ray Attenuation Coefficients for Crystallography (J. H. Hubbell)

New and independent measurements of x-ray attenuation coefficients, in well-characterized single-crystal silicon samples, have been made in 12 cooperating laboratories in Australia, Denmark, India, Japan, Malaysia, U.K., U.S.A., and Yugoslavia, constituting the first results of the International Union of Crystallography (IUCr) Commission on Crystallographic Apparatus X-Ray Attenuation Project. This project, as originally proposed by NBS and inaugurated at the 1978 Warsaw Congress (IUCr-11), is aimed at resolving serious discrepancies in the data in the literature. In a manuscript for Acta Crystallographica, coauthored with the Project Chairman (D. C. Creagh, Australia), these measurements are compared with available theoretical values and with previous measurements in the photon energy range 8 to 1173 keV. This evaluation suggests that present compilation values for silicon should be lowered by amounts of the order 5 percent in the region 20 to 50 keV and also that measurements in silicon would be useful in the important region 0.277 to 6.4 keV, where no measurements have been made to date.

The samples for this project have been fabricated and distributed to 23 laboratories by the Chairman (Creagh, Australia), and the NBS serves as Project Secretariat. Measurements are being made also on copper, germanium, magnesium, and pyrolytic graphite, which will be similarly evaluated and reported in the crystallographic literature. Results of this project will be taken into account in Sections 4.2.3 (X-Ray Absorption Coefficients Commentary) and 4.2.4 (X-Ray Absorption Coefficients) invited for the International Tables for X-Ray Crystallography (Vol. C, new series) in coauthorship with Creagh.

Critical Analysis of Soft X-Ray Cross Section Data (M. J. Berger & E. B. Saloman)

A pilot project is in progress in the NBS Photon and Charged Particle Data Center to collect and evaluate photon cross section data in the soft x-ray region 100 eV to 10 keV. These data will provide input for compiling tables of recommended cross section values for a variety of technological and basic research applications. This project complements earlier NBS evaluations and compilations which focused primarily on energies above 10 keV. In the present region of interest (soft x ray) the total cross section (attenuation coefficient) consists almost entirely of photoabsorption, with coherent and incoherent scattering contributions significant only for the low Z elements. The NBS collection of experimental total attenuation coefficients abstracted from the literature is now computerized to facilitate use and for future updating. These experimental data have been compared for several key elements with theoretical photoabsorption (Livermore) in the range 1 to 100 keV. Stimulated by this NBS soft x-ray data project, Scofield has made new photoeffect calculations extending down to 100 eV which will be similarly compared with available measurements. In addition, at the request of the NBS Photon and Charged Particle Data Center, Doolen (Los Alamos) is doing new calculations extending from 10 keV down to the eV region using the time-dependent local-density approximation programs developed by Liberman and Zangwill, which will also be compared with the NBS measured-data collection as a NBS/LANL collaboration.

Penetration of Radiation Through Multi-Layer Media S. M. Seltzer & M. J. Berger)

The Monte Carlo program ZTRAN has been debugged, and has been described in a National Bureau of Standards report, NBSIR 84-2131. This is a 1-D program which can be used to calculate the penetration, diffusion and slowing down of electrons and/or photons in a medium consisting of several slabs of different materials adjacent to each other. Comparisons have been made in regard to energy deposition in various multilayer combinations, and indicate good agreement between predicted and experimental depth-dose distributions. Other typical problems, involving electrons

with energies from 500 keV to 60 MeV, and various multilayer configurations (e.g. Al/Au), have been treated to indicate the utility of the program. These results have been presented in an invited paper at a Conference on the Application of Accelerators in Research and Industry (November 12-14 1984), and will be described more fully in a paper now in preparation.

Proton Energy Loss Straggling (M. J. Berger)

In the modeling of radiation effects on the cellular or subcellular level, one often needs information about proton energy-loss straggling in very short pathlengths (micrometers or fractions of micrometers). The classical straggling theories of Landau and Vavilov have the limitation that they apply only to sufficiently long pathlengths, and may be inaccurate for the distances often of interest in radiobiological modeling. An alternative Monte Carlo method was therefore developed which is not subject to this limitation and can be applied to arbitrarily short distances. This method has been implemented for a water medium, using reliable ionization cross sections that have recently become available. Energy loss distributions in water have been calculated for protons with energies between 0.5 and 20 MeV traversing pathlengths from 1 to 1000 mean-free paths. The results indicate that the theories of Landau and Vavilov (supplemented by the Blunck-Leisegang correction) provide accurate results only for pathlengths greater than about 100 mean-free paths.

Charged-Particle Spectra and Kerma Factors (J. J. Coyne, H. M. Gerstenberg, and R. S. Caswell)

Methods have been developed for the systematic tabulation of the energy spectra of charged particles released in neutron interactions with tissue or tissue-equivalent solids and gases. The spectra treated include both the initial spectra resulting from the nuclear interactions and the energy-degradation spectra resulting from the inelastic Coulomb scattering of the released charged particles as they slow down to rest. The computational apparatus has been prepared for an extensive compilation which will be useful for biophysicists engaged in the modeling of radiation effects. Kerma factors (which are in effect energy-weighted integrals over the initial spectra) have been calculated for H,C,N and O in neutron energy bins 200 keV wide, covering the region from 0 to 20 MeV, and also for 76 logarithmic bins extending from thermal energies to 2 MeV. The information generated includes the contribution to the kerma factors from different particles and from different reactions. The publication of the kerma factors has been delayed because of the uncertainty of the results for alpha particles for neutron energies above 10 MeV. The variation of kerma due to alpha particles in the reaction $^{12}C(n,n')3\alpha$ has recently been investigated and the results of this study will be used to improve the kerma tables before publication.

Microdosimetry for Neutrons (J. J. Coyne, H. M. Gerstenberg, & R. S. Caswell)

The analytical transport theory developed at NBS uses the continuous-slowing-down approximation to calculate energy deposition in small sites by secondary charged particles released in neutron interactions with tissue. Efforts are now underway to refine the method by including the effects of energy-loss straggling of protons, and the effects of energy transport by secondary electrons released in proton-impact ionization events. Two approaches are being used: (a) the incorporation of straggling information into the analytical method; and (b) independent Monte Carlo calculations. Pilot calculations made for 20-MeV and 14-MeV neutrons and spherical 1-micrometer sites indicate that the straggling effects are small but significant, and that the inclusion of these effects will improve the agreement between calculated and measured microdosimetric event-size distributions.

Neutron Transport and Dosimetry (C. M. Eisenhauer)

Calculations and measurements designed to characterize the neutron and gamma-ray fields in the exposure rooms of the Armed Forces Radiobiology Research Institute (AFRRI) have continued. Measurements of neutron spectra made by Science Applications International Corporation (SAIC) using activation foils were benchmarked by irradiating them in the NBS ^{235}U fission neutron spectrum. Predictions of neutron fluence by individual detectors showed departures of as much as 10 percent from the NBS fluence. These biases must be taken into account when interpreting other measurements by SAIC in AFRRI neutron fields. In addition, NBS made measurements in the AFRRI exposure room 1 configured with a 6-inch Pb shield. Analysis of these data showed that measurements with six activation/fission foils together with the NBS spectrum adjustment code SPAD could be used to obtain a kerma rate that agreed to within 1 percent with the value obtained with tissue-equivalent ionization chamber.

Calculations were made with the ANISN computer code to aid in the design of the shielding for a ^{252}Cf neutron check source for AFRRI.

In order to improve the NBS capability for calculating neutron and gamma-ray transport, a Monte Carlo computer code MCNP has been obtained from Los Alamos National Laboratory. Videotapes of a workshop on the use of the code were also obtained. The code has been compiled on the CYBER 855 computer. Test runs will commence shortly.

International Radiation Physics (J. H. Hubbell)

For the Third International Symposium on Radiation Physics (ISRP-3), Ferrara, Italy, Sept. 30 - Oct. 4, 1985, John Hubbell served as Secretary for the International Programme Committee and Bill Ott and Martin Berger

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were members of the ISRP-3 International Advisory Board. This Symposium is a sequel to ISRP-1 (Calcutta 1974) and ISRP-2 (Penang 1982), in both of which NBS played major supporting roles (Ed Brady arranged publication of ISRP-1 Proceedings as NBS-SP-461; Hubbell gave keynote address and performed other organizing tasks). ISRP-3 is sponsored by the European Physical Society and the Societa Italiana di Fisica, with support from eleven other Italian scientific institutions, and has a scope including the following topics:

(1) Cross sections for interactions between radiation and matter, and other physical parameters characterizing the primary events induced by radiation in matter; (2) radiation transport; (3) properties, planning and preparation of radiation sources; (4) properties and realization of radiation detectors; (5) radiation physics in fundamental research; (6) radiation physics in biomedicine and environmental science; (7) radiation physics in technology and energy research; and (8) radiation physics teaching at the university level.

II. Radiation Chemistry and Chemical Dosimetry Group

The program of the group deals with investigations of radiation effects in chemical and biological systems from the early physical interaction of radiation and matter to final biological endpoints and the dosimetry of radiation effects.

Radiation Chemistry (M. G. Simic, E. P. Hunter, L. Karam, W. L. McLaughlin, M. Dizdaroglu, D. Bergtold, & M. AlShiekhly)

The associated chemical and biological processes are studied from a kinetic and mechanistic point of view at a molecular level. That approach requires investigation of transient free-radical species by fast kinetic techniques (pulse radiolysis), product measurement by a variety of analytical techniques (GC/MS, HPLC, spectroscopy, etc.), and characterization of bio-effects by suitable bio-chemical techniques (centrifugation, electrophoresis, etc.). The investigations are conducted in both simple and complex model systems, as well as in cells. Cells are used because no model systems can mimic the microenvironment of DNA in living systems.

The major emphasis of the research is on damage and repair of DNA. Since DNA is associated with proteins (histones) and is attached to membranes, some aspects of radiation chemistry of amino and fatty acids are also being investigated. The interest has, however been focused predominantly on the mechanisms of DNA base damage and crosslinking of DNA within and with proteins. Crosslinking appears to be a major effect in cells. Mechanisms and consequences of crosslinking however, are not yet understood because of the measurement problems. Irradiation parameters (dose, dose rate, temperature, state, O_2, etc.) are of critical importance since the effects of radiation can be qualitatively and quantitatively altered

by them. The effects of quality of radiation (LET) are not investigated at present. However, the study of the effects of low energy protons and α-particles, as well as high energy high Z nuclei (BEVALAC) are in the planning stage.

Impact. This research is expected to have an impact in radiation biology, radiation therapy of cancer, cancer etiology, risk assessment, radiation protection, and irradiation processing in general. Specifically, it is relevant to: safety assessment of irradiated meats, assessment of damage by low-LET radiations (γ and x rays, electrons) vs. α-particles (e.g. radon), and development of standards for individual biological sensitivity to radiation.

Chemical Dosimetry (W. L. McLaughlin, M. G. Simic, B. Radak, M. Farahani, & W. Warasawas)

The investigated radiation effects, with kinetic and mechanistic understanding, are subsequently utilized in the development of new methods and concepts for radiation dosimetry. Currently, the activities are devoted equally to the development of novel and improved systems.

For convenience, the chemical dosimetry program is subdivided into the following areas:

On-Line Dosimeters (OLD). This is a classical type of dosimeter which is carried for personnel protection or is attached to samples to be irradiated. Optical wave-guide (OWG) dosimeters conceptually developed in this lab in the previous years, have been shown to be suitable as personal dosimeters, with lower sensitivity of about 1 rad. Further development is in progress to increase their sensitivity to allow accurate dose measurements of about 10 mrad.

Research on dosimeters for (a) multi Mrad dose range, and (b) neutrons (mixed low-and high-LET) is in preliminary stages.

Real-Time Dosimeters (RTD). Convenient chemical dosimeters which could be read during irradiation are not available commercially. OWG dosimeters have been adopted for low dose-rate real-time measurements, by using common green and yellow LEDs and silicon photodiode and DMSO solutions of HHEVC. Further development is needed for RTDs with possible application in radiation therapy and emergency dosimetry.

There is also need for the development of standard RTDs for ultra-high dose-rates, with applications in nuclear weaponry and pulse radiolysis measurements (ns-μs, up to 10^{15} rad/s).

Post Irradiation Dosimetry (PID). There are numerous instances when the knowledge of the delivered radiation dose is required either immediately or long after the exposure. For example, proof that suspected foods have or have not been irradiated is required by food processors and wholesalers for purposes of regulation of import/exports. Reliable measurements which can indicate that irradiated foods have not received radiation dose in excess of the legal limits are needed by regulatory agencies. Finding of DOPA in irradiated chicken meat may be utilized for the development of suitable PID for meats.

Accidental exposure of personnel to radiation has occurred in some cases without an adequate OLD being present, accentuating the need for the development of novel concepts in RTD and PID for such circumstances.

Measurements of the total energy delivered (J) to a patient in radiation therapy would be useful information to a therapist. Possible presence of unique radiolytic products, URPs, in the urine of irradiated patients or personnel in space is under investigation.

Achievements

Mechanisms of DNA Damage

1. Reaction mechanisms and distributions of OH radical attack on thymine, uracil and their derivatives were determined by pulse radiolysis. Reducing radicals were shown to be formed in excess. On oxidation of these reducing (6-yl) radicals by oxidizing agents pyrimidine glycols are produced. Mechanisms of the thymine glycol formation is important for the understanding of finding of thymine glycol in the urine, which reflects the extent of damage to DNA. It is hoped that thymine glycol will be used as an internal dosimeter of exposure to genotoxic agents. (Jovanovic, Simic)

2. Novel crosslinks and their mechanisms of formation were discovered for sugar-thymine and sugar-phenylalanine, which indicates a possible role of deoxyribose in radiation-induced DNA-protein crosslinks in cells. Radiation-induced crosslinking of DNA to proteins has been shown recently to be one of the major effects of radiation in cells. However, the molecular mechanism and its biological significance are not known at present. (Farahani, Karam, Dizdaroglu, Simic)

3. Novel intramolecular mechanism of strand break formation was discovered which operates via addition of OH radical to thymine, T, and subsequent H atom abstraction by the resulting radical, •T-OH, from a neighboring deoxyribose. The •T-OH radical cannot abstract H from a sugar to which it is attached. Hence, the

following mechanism has been proposed T-S-P-S-T-OH → T-S-P-S-THOH, since the product THOH has been isolated. These indirect routes to strand breaks may be of importance in understanding the mechamism of radiation-induced DNA double strand breaks which is a major cause of deleterious effects of radiation. (Dizdaroglu, Karam, Simic)

Radioprotection

A new role for uric acid, a suggested dietary antioxidant, was discovered. Uric acid was found to be a potent repairing agent of oxidative damage to DNA bases and as such, may play a significant role in protection against mutation, cancer, aging and radiation injury. Further work is needed to establish its significance as an endogenous protector of DNA. (Jovanovic, Simic)

Chemical Dosimetry

1. Important advances in the development of OWG dosimeters have contributed to: (a) commercialization of a first OWG food irradiation dosimeter; (b) development and testing of an emergency personnel and environmental dosimeter. These dosimeters have been shown to be suitable for the measurement of 1-100 rad. They also promise further increase in sensitivity for application to the <1 rad region. Their application to the 30-100 krad region in food irradiation processing is also of interest because of lack of suitable dosimeters for that range of dose and the approval of FDA up to 100 krad for food irradiation. (McLaughlin, Radak)

2. Several new organic detectors of radiation have been shown to be suitable for dosimetry applied to biology and medicine. These organic systems have sufficient accuracy and reproducibility, as well as energy absorption properties, of bio-systems. Energy dependence characteristics for photon energies down to a few keV demonstrate their applicability to dose measurements in muscle, bone, and adipose tissue. (McLaughlin)

3. Mechanisms of radiation-induced color changes of leuco dyes in radiochromic dosimeters, not understood so far, have been resolved by pulse radiolytic investigation of model dye systems. It was shown that solvated electrons eliminate cyanide from a leuco form of a dye (no color) in the first step. The resulting dye radical is then oxidized to a carbocation (colored) by oxygen. (AlSheikhly, McLaughlin)

4. DOPA has been found in irradiated chicken meat, which normally contains much lower levels. This radiolytic product originates from an OH radical reaction with tyrosine, one of the 20 most common amino acids in proteins. The product can be utilized for post-irradiation dosimetry in meats. At present, methodology to tell whether meat has been irradiated does not exist. Availability of such a method is of great importance in regulating irradiation processing of meats (pork in particular) and prevention of illegal importation of irradiated shrimp, frog legs, etc. (Dizdaroglu, Simic)

Conferences (M. G. Simic)

Major international conferences on the mechanisms of radiation and free-radical damage to bio-systems and their repair have been organized and new ones are in the preliminary organizational stages. The goal of these conferences has been to promote preventive aspects and protection from hazardous agents at the molecular level. In that series are the following conferences: (1) Autoxidation in Foods and Biological Systems, 1979; (2) 1st Conference on Radioprotectors and Anticarcinogenesis, 1982; (3) Mechanisms of DNA Damage and Repair. Implications for Carcinogenesis and Risk Assessment, 1985; (4) 2nd Conference on Anticarcinogenesis and Radiation Protection, 1986; and (5) IV International Congress on Oxygen Radicals, 1987.

III. Neutron Measurements and Research Group

This group is concerned with measurements of neutron interactions which depend strongly on the neutrons' energy. The interactions include both nuclear and molecular effects and require neutron spectroscopic capability from 0.005 eV to 50 MeV--over ten decades of energy. The largest program is devoted to a continuing international effort to push the accuracy of reference neutron cross sections into the ±1 percent (1 SD) range. Other programs are concerned with the development and exploration of analytical techniques based on the unique features of the neutron's interaction with matter. Both the standards and analytical studies require a significant component of fundamental neutron research. The NBS facilities used are the 100-MeV linac, 3-MV positive-ion Van de Graaff, and nuclear reactor. A list of the group's technical activities follows.

Absolute Measurements of the $^{235}U(n,f)$ Cross Section for Neutron Energies from 0.3 to 3 MeV (A. D. Carlson, J. W. Behrens, R. G. Johnson, & G. F. Cooper)

Measurements of the ^{235}U neutron fission cross section have been made at the NBS neutron time-of-flight facility. The neutron flux was measured at the 200-m end station with a Black Neutron Detector. The ^{235}U fission reaction rate was determined with a fission chamber located on the same beam line at 69 m from the neutron target. The data have been analyzed

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and the results were given at the recent IAEA Advisory Group Meeting. The final data including extensive information on correlations and uncertainties are being used in the upcoming ENDF/B-VI evaluation of the neutron cross section standards. In the 0.3-1.2 MeV region the present measurements are generally in good agreement with two earlier NBS measurements using the linac and Van de Graaff facilities; however, the present data are systematically slightly lower than the previous measurements. All three data sets are lower than the ENDF/B-V evaluation. The present measurements are also lower than the evaluation in the higher end of the energy region.

Application of the Dual Thin Scintillator Neutron Flux Monitor in a $^{235}U(n,f)$ Cross Section Measurement (M. S. Dias, R. G. Johnson, A. D. Carlson, & O. A. Wasson)

A measurement of the $^{235}U(n,f)$ cross section in the 1.0 to 6.0 MeV range has been made at the same NBS neutron time-of-flight facility as the preceding measurement. The dual thin scintillator (DTS) neutron detector was used as the flux monitor. This detector was placed in the 200-m end station. The ^{235}U fission reaction rate was determined using a fission chamber containing deposits of ~ 100 $\mu g/cm^2$ located on the same beam line at 69 m from the source. The data from this measurement have been analyzed and the results have been reported in a paper at the recent IAEA Advisory Group Meeting.

Since the present measurement was intended primarily as a test of the DTS detector as a flux monitor, only moderate energy resolution (~ 10 percent was planned. The statistical precision is 1.0 percent at 1.3 MeV and 2.1 percent at 6.0 MeV. In the region of overlap there is excellent agreement between the present measurement and the measurement using the Black Detector data. While the overall agreement with ENDF/B-V is good the data tend to be lower than the evaluation below 2.5 MeV and higher than the evaluation between 2.5 and 3.5 MeV.

Measurements of the Ratio of the $^{10}B(n,\alpha)^7Li$ to $^6Li(n,t)^4He$ Cross Sections in the eV Energy Region (A. D. Carlson)

A previous measurement at NBS of the $^{10}B(n,\alpha)$ to $^6Li(n,t)$ cross section ratio was initiated in order to determine if the discrepancy between two sets of $^{235}U(n,f)$ cross section measurements from other laboratories was a result of the detectors used for determining the neutron flux. Our previous measurement did not explain the ^{235}U discrepancy but did show an apparent difference of 1-2 percent below 20 eV in the $^{10}B/^6Li$ ratio compared with the ENDF/B-V cross sections. The present measurements were made in order to further study the effect.

The present experiment employs essentially the same equipment and setup as was used in our previous work. The $^{10}B(n,\alpha)$ and $^{6}Li(n,t)$ rates were measured with a ^{10}B plated ionization chamber and a thin natural lithium glass detector located at the 20-m station of the NBS neutron time-of-flight facility. Lower backgrounds were obtained in the present work through improvements in shielding and the use of a narrower pulse height window for the ^{6}Li detector. Additional Rh and Pt beam filters reduced the systematic error due to the interpolation of the background. The present measurements agree with the ENDF/B-V evaluations. The previous measurement was probably affected by systematic errors in the background subtraction.

The results of the present study were submitted for publication. Though this work has been completed, further studies are being performed with these detectors in order to determine if it is possible to extend the results to higher neutron energies.

Development of Boron-Uranium Fission Chamber for Cross Section Measurements in the eV Energy Region (R. A. Schrack)

A composite ionization fission chamber was designed, constructed, and initial measurements have been made. The device incorporates both ^{10}B and ^{235}U foils intermixed in the same chamber filled with 1 atmosphere of P-10 gas. Computer simulations of pulse height distribution have been verified by experimental measurements. Filters of cobalt, manganese, gold, rhodium, and platinum have been used to measure the background for the boron and uranium detector systems. Preliminary results indicate about a 1 percent background that is independent of energy for both systems.

Multiple scattering, self-shielding, and backscattering calculations have been made and indicate effects less than 1 percent. A relative measurement of the $^{235}U/^{10}B$ cross-section ratio is underway that will cover the energy range from thermal to 1000 eV. Foil uniformity and total mass, counts below threshold, and detector efficiency will then not affect the precison of the measurement. Work is now continuing on preliminary tests and the required two-parameter, two-experiment data acquisition system. Because of the large energy region spanned by the experiment it will be necessary to incorporate an "accordion" system that will have several changes in energy resolution over the range covered.

Development of a Standard 2.5 MeV Neutron Beam (K. C. Duvall)

The recent purchase of a 100 keV, 0.5 mA ion generator will permit the development of a standard 2.5 MeV neutron beam. The neutron source will be produced by the $D(d,n)^{3}He$ reaction in which the output will be determined by associated particle measurement. The high accuracy measurement capability of the time-correlated associated particle (TCAP) method

will be utilized to carry out standard cross section measurments to accuracies of the order of ±1 percent. The neutron beam facility will be used to measure the $^{235}U(n,f)$, $^{239}Pu(n,f)$, $^{197}Au(n,\gamma)$, and $^{3}He(n,p)$ cross sections at 2.5 MeV. It is intended that this measurement effort contribute significantly to the establishment of 2.5 MeV as a high accuracy normalization point between the spot energies of 14 MeV and thermal.

Analysis of the Effect of Random Events on the 14 MeV $^{235}U(n,f)$ Cross Section Standard Measurement (O. A. Wasson, A. D. Carlson, & K. C. Duvall)

The most accurate measurements of the $^{235}U(n,f)$ cross section at 14 MeV neutron energy have used the Time-Correlated Associated-Particle Technique (TCAP) with the $T(d,n)^{4}He$ reaction. These measurements, using three independent ^{235}U mass standards, are in excellent agreement (1 percent).

However, it has recently been suggested that some of these published measurements should be changed because of the effect of random events on the coincidence timing. Since the NBS conditions differed from those encountered in many other similar experiments, a detailed analysis of the NBS experiment and the electronic suppression of coincidence losses due to random events was performed. The unique combination of electronic components incorporated in the experiment eliminated the effect of losses due to random events in the timing analyzer. There is, thus, no correction to apply and no change in the published value of the NBS measurement is warranted. This analysis has been submitted for publication.

Development of the Dual Thin Scintillator (DTS) in the Coincidence Configuration as a Neutron Spectrometer (K. C. Duvall & R. G. Johnson)

The Dual Thin Scintillator (DTS) has been designed and built at the NBS for use as an absolute neutron flux monitor in the energy range of 1-20 MeV. The DTS detector consists of two thin, back-to-back plastic scintillators optically separated from each other and independently coupled to photomultiplier tubes. The detector may be operated in the coincidence configuration where only simultaneous events in both first and second scintillator are recorded. The events recorded in the coincidence configuration are due primarily to proton recoils that are produced in the first scintillator and pass into the second scintillator. The energy distribution of the proton recoils recorded is affected by the range of the recoil particles and is determined by the angles allowed for path lengths reaching into the second scintillator. The detector pulse height distribution consists, therefore, of contributions from the more forward scattered, higher energy proton recoil events and exhibits a more peaked response, centered at the incident neutron energy. This is a more favorable response function to be used with spectrum unfolding techniques and should provide improvement over spectral determinations with conventional proton recoil response functions.

Neutron Resonance Transmission Analysis for Nondestructive Evaluation of Proximity Fuzes (R. G. Johnson & R. A. Schrack)

In collaboration with Harry Diamond Laboratories we have recently applied the technique of neutron resonance transmission analysis (NRTA) to nondestructively evaluate (NDE) the power supplies of M732 proximity fuzes. Some of these power supplies, which are simple lead-acid batteries, were failing when the acid leaked from its ampule into the normally separate volume containing the lead plates. In addition to the acid, a buffering agent, methylene bromide, is contained in the ampule. The NRTA technique was used to detect the presence of bromine (using the 35.8-eV resonance) in part of the battery containing the lead plates. Measurements were performed at the NBS neutron time-of-flight facility where the fuze was placed at 5.4 m from the source and the neutron beam was collimated to a 3.2 cm by 0.7 cm area. Transmitted neutrons were detected at 6.7 m by a ^{6}Li-glass scintillator (4.4-cm diameter by 2.5-cm thick). Originally it was expected that the observation of bromine would be difficult because only the presence of methylene bromide vapor was anticipated. However, experimentally a strong bromine resonance was observed in known bad batteries. We found that the methylene bromide was being concentrated because it attacked the plastic case of the battery.

For a full test of the method four cases (32 fuzes) of fuzes were received from HDL for testing. The condition of the power supplies in these fuzes was unknown. After testing at NBS the fuzes were returned to HDL where they were disassembled and checked for leaking power supplies. Although both false positive and false negative identification of leaking power supplies were seen in the results, the cause of these problems is well understood and can be eliminated. The NRTA technique can be a viable method to screen M732 proximity fuzes.

The final phase in this project was the specification of design parameters for a portable linac to implement NRTA for screening the M732 fuze stockpile and the identification of vendors for such a linac. The linac could be moved to the storage locations and fuzes could be examined at an effective rate of 15-45 seconds per fuze.

Measurement of the NBS Black Neutron Detector Efficiency at 2.3 MeV (K. C. Duvall, A. D. Carlson, & O. A Wasson)

The absolute efficiency of the NBS Black Neutron Detector at 2.3 MeV has been measured using the time-correlated associated particle method. Until recently, the NBS Black Neutron Detector had been utilized only in the limited energy range of 0.2 to 1.2 MeV, where the efficiency determination from Monte Carlo calculations has been verified by experiment. A result of 0.760 has been obtained for the Black Neutron Detector efficiency at 2.3 MeV with an experimental uncertainty of ±1.2 percent and agrees well with the Monte Carlo calculated value. The measurement extends the

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usefulness of the Black Neutron Detector as an absolute neutron flux monitor to the higher energy region and in fact has been used to measure the $^{235}U(n,f)$ cross section from 0.3 to 3.0 MeV. This result has been published.

Detector Development for eV Scattering Spectrometers (R. G. Johnson)

Detector development for resonance detector spectrometers (RDS) to extend neutron scattering studies to the eV region has continued. In this technique the energy of the scattered neutron is defined by a low energy nuclear resonance. Previously the use of a large area planar HPGe detector which detects the x rays from internal conversion of γ rays following neutron capture was shown to provide good efficiency and good background rejection. Since in the internal conversion process both an electron and an x ray are emitted, detecting both signals in coincidence can improve the background rejection. To test this method two thin gold foils (3-μm thick) were placed between three 1.0-mm thick plastic scintillators. Electrons detected by the plastic scintillator provided a coincidence gate for the HPGe detector.

The results of this initial measurement show that even with this less than optimum foil and scintillator thicknesses, an improvement of ~ 2.5 in the signal to background ratio was observed when operating in the coincidence mode as opposed to the non-coincidence mode.

International Intercomparison of Neutron Flux Measurement Capability at 500 keV (A. D. Carlson, R. G. Johnson, & O. A. Wasson)

A final report on the NBS participation in an international intercomparison of neutron flux measurement capability sponsored by the Consultative Committee for Ionizing Radiations (CCEMRI) at BIPM has been prepared and sent to AERE Harwell, the organizing laboratory. This intercomparison which uses a large ^{235}U fission ionization chamber allowed both linac and Van de Graaff neutron facilities to be used. The detector efficiencies measured at 500 keV at the linac and Van de Graaff facilities at NBS agree well within the 1.7 percent total error for each measurement.

Data Acquisition System Improvements (R. G. Johnson)

The first computer system to replace one of our three Harris /5 systems is on order and should be delivered in September. The computer ordered is a Charles River Data Systems Universe UV2403FT-E which is based on the Motorola 68000 microprocessor on the VME bus. As a replacement this computer can be expected to provide a factor of ~ 10 improvement in most aspects of our data acquisition capabilities.

The Neutron Cross Section Standards for the National Evaluated Nuclear Data File, ENDF/B-VI (A. D. Carlson, W. P. Poenitz (ANL), G. M. Hale (LANL), and R. W. Peelle (ORNL))

This sixth evaluation effort under the leadership of Carlson is following a different process than that used for previous versions. The primary effort is concentrated on a simultaneous evaluation using generalized least squares, R-matrix evaluations and a procedure for combining the results of these evaluations. The simultaneous evaluation is important to this process since ratio measurements in addition to shape and absolute determinations are treated properly. Correlations within and among experimental data sets are also taken into account.

The R-matrix evaluations provide a method which allows charged particle measurements involving the same compound nuclei (^{7}Li and ^{11}B) to be included in the evaluation process. These evaluations also provide a smooth meaningful expression for the energy dependence of the cross sections. Independent data bases are used in the simultaneous and R-matrix evaluations. The combining procedure is used to combine the information obtained from these analyses in a proper way to form the final evaluation and its variance-covariance matrix. The standards being evaluated are $^{6}Li(n,t)$, $^{10}B(n,\alpha_1)$, $^{10}B(n,\alpha)$, $^{197}Au(n,\gamma)$ and $^{235}U(n,f)$. Evaluations for the important reactions $^{238}U(n,\gamma)$, $^{238}U(n,f)$, and $^{239}Pu(n,f)$ are also being performed.

Preliminary results of the evaluation process with overlapping and non-overlapping data bases have been reported at recent nuclear data meetings. Efforts are now underway to further improve the grouping of the data bases for the simultaneous and R-matrix analyses. Also a new concept involving the thermal constants is being implemented. This will allow the relevant thermal constants to be evaluated simultaneously within the framework of the standards evaluation.

Efforts have been and continue to be made to handle the various parts of the evaluation process in a proper and defensible way. Significant progress has been made but the process is complicated and time consuming. It is anticipated that final combination results, i.e., adjusted R-matrix parameters for the lithium and boron cross sections and pointwise values for the $^{197}Au(n,\gamma)$ and $^{235}U(n,f)$ cross sections, will be available in early 1986.

Development of Rutherford Backscattering Facility for Analysis of UO_2 Samples (O. A. Wasson, W. E. Slater, & H. Frederikse)

A Rutherford Backscattering (RBS) facility was established on a new beam line at the 3-MV positive ion Van de Graaff laboratory. This facility, in collaboration with scientists from the Center for Materials Science, is being utilized for studies of the areal density distribution

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of uranium deposits used in neutron cross section measurements. A versatile scattering chamber with numerous ports, 5 axis goniometer, target ladder, and solid state detector is in operation. In addition to the hydrogen and deuterium beam used for neutron production, the accelerator was modified to produce 1.3 MeV He^+ beams with currents as large as 10 microamperes and 5-MeV He^{2+} beams with currents as large as 100 nanoamperes. The variation in areal density of a 75 cm diameter UO_2 deposit was measured using a 1 MeV He^+ beam. The results are in excellent agreement with those obtained from α-activity measurements.

Profile of UO_2 Deposits by α-Particle Counting (R. A. Schrack)

Deposits of ^{235}U in the form of UO_2 on aluminum backing were obtained from Oak Ridge National Laboratory. The deposits are three inches in diameter and vary in uniformity. Use of the foils in a fission chamber being built to measure the ^{235}U fission cross section requires a knowledge of the deposit uniformity. Fortunately, the material used to produce the uranium deposit had a 0.99 percent contribution of ^{234}U. This isotope has a relatively high probability of decay by α-particle emission. Assuming that there is no isotopic separation during deposition, the ^{234}U distribution can be measured by α-particle detection to determine the ^{235}U distribution. A collimator system for the α-particle detector was designed and its efficiency and response function determined by a Monte Carlo program. The results from the measurements are in good agreement with those from Rutherford Backscattering and show that the density of the deposit drops by at least 10 percent from the center to the edge. This variation is acceptable if the fission chamber is to be used for relative measurements but will necessitate careful measurement and corrections for absolute cross section measurements.

Neutron Resonance Transmission Analysis of Reactor Fuel Samples (J. Behrens, R. Johnson, and R. Schrack)

Neutron resonance transmission analysis has been used to measure the isotopic content of fresh and spent nuclear reactor fuel samples. Our final results have been published.

He-3 Gas Scintillation Counter (J. W. Behrens)

The NBS ^3He gas scintillation counter is a dual-windowed, cylindrical gas cell with a pair of RCA 8850 photomultipliers viewing a gas mixture of 48 percent ^3He/52 percent Xe (nitrogen 30 ppm). The pyrex glass windows are coated with 30 $\mu gm/cm^2$ DPS wavelength shifter. The stainless steel cylindrical section of the cell is coated with a 1000 Å layer of aluminum. In November 1983 this counter was pressurized to 30 psia. Since that time, it has been thoroughly studied at the NBS linac, Van de Graaff, and Reactor facilities.

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In the published literature on gas scintillation counters, researchers usually recommend continuous gas purification to reduce degradation of the ultraviolet light output, due to trace impurities such as oxygen. Even with gas purification, they warn that one can reasonably expect only several months of stable operation before significant degradation starts. Amazingly, our detector has been working for over 21 months with no significant loss ($\leq$ 5 percent) in light output and it has no continuous gas purification. We measure our counter's light output relative to the single photoelectron peak from the matched photomultipliers. We have clearly found a design which can ensure stable operation over a reasonable time period without the need for a costly and perhaps complex continuous gas purification system. This greatly simplifies the detector's design and significantly reduces its cost.

The energy resolution of our present design, however, must be improved to ensure accurate subtraction of the ^{3}He-recoil pulse height spectrum from the total pulse height spectrum measured. Computer modeling using the Monte Carlo technique will help determine the shapes of the ^{3}He-recoil spectrum and the desired ^{3}He(n,p)T spectrum. To improve the energy resolution of the detector, we are incorporating into our design concepts from the "Gas Proportional Scintillation Counter" (GPSC). GPSCs typically use an applied electric field to enhance light output by accelerating the electrons from the initial ionization. Light output can be magnified by several orders of magnitude and at the same time, the energy resolution can be improved to rival or even better that from a conventional gas proportional counter ($\Delta E/E \cong 10$ percent). From the GPSC, fast timing is obtained from the "prompt" scintillation pulse; whereas, improved energy resolution is obtained from the slower "secondary" scintillation pulse.

Work is presently in progress on incorporating GPSC concepts into our design and on refining our computer codes to calculate the shapes of the ^{3}He-recoil and ^{3}He(n,p)T pulse-height spectra. We feel confident in our choices of 30 μgm/cm^2 DPS evaporated only on the glass windows of the cell and of the RCA 8850 photomultiplier. Our design can ensure stable operation over reasonable time periods without the need for continuous gas purification.

Guest Scientist at Centre d'Etudes de Bruyères-le-Châtel, France
(J. W. Behrens)

J. W. Behrens returned to NBS on January 1, 1985 after completing a one year assignment as a guest scientist at Centre d'Etudes de Bruyères-le-Châtel, France. During his assignment he participated in "Cold Fragmentation" fission measurements and in studies of the fission cross section systematics of the actinides for MeV neutrons. Publication of both of these investigations is in progress.

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The evolution of a fissioning nucleus from saddle point to scission is perhaps the least known stage of nuclear fission at low energy. The cold configuration is particularly interesting to study because it makes available to experiment the primary fragmentation, as the fragment excitation energy is low enough that no neutrons are emitted. In the present measurements, we investigated cold fragmentation in the thermal neutron-induced fission of ^{235}U, i.e., ^{236}U, to test the fission dynamics calculation and to contribute to the knowledge of the even-odd effect and of the maximum total fragment kinetic energy for a given fragmentation.

In addition to obtaining nuclear data from measurement and theory, one may also rely on the study of systematic trends in nuclear parameters which are accurately known to infer these parameters for nuclides which are not accurately known, often because they are difficult to measure. The present study has the goal of inferring σ_{nf} values to an accuracy of within ±10 percent for selected, short-lived ($t_{1/2}$ < 100 years) actinides from trends observed in σ_{nf} values for their longer-lived, measured neighbors. Results for a total of over 40 isotopes of the uraniums, neptuniums, and plutoniums have now been completed. Extension of these trends to the transplutoniums, however, yields inferred values which significantly overpredict the fission cross section. This overprediction is primarily caused by the change in the systematics of the inner fission barrier height near compound nucleus neutron number 146.

The Development of a 6-to-7 MeV Photon Field for Instrument Calibration
(K. C. Duvall)

Improvements in the 6 to 7 MeV photon source characteristics and measurement capabilities continue. The proton incident beam energy has been increased to 2.7 MeV which has resulted in an increase of at least a factor of two in the high energy photon yield. The increased photon yield is expected to allow absorbed dose measurements to be carried out with a small ion chamber as well as with thermoluminescent dosimeters. Also, analysis codes used in unfolding NaI pulse-height data have been transferred and implemented on the new NBS central computing system. The spectrum unfolding analysis, which requires a substantial allocation of memory, benefits from the increased computing capability of the new central computer.

Conceptual Design of an Induction Linac for Neutron Research
(R. G. Johnson)

The induction linac originally discussed in the recent Neutron and High-LET Radiation Program Analysis report has been redesigned to take advantage of recent developments in induction accelerator technology. The major question in the original design concerned the design of the pulse forming network. Since that time, the work on magnetic pulse compression

at Lawrence Livermore National Laboratory has been successfully completed. Incorporating this work in the design of an induction linac settled this critical question and provided further simplification in the design of induction modules. A report on the improved design was presented at the International Conference on Nuclear Data for Basic and Applied Science (May 13-17, 1985, Santa Fe, NM).

Measurement of the Isotopic Composition of an Uranium Sample
(R. A. Schrack and O. A. Wasson)

The isotopic composition of an uranium sample for use in a crystal spectrometer at the University of Alberta was measured by use of neutron resonance radiography at the linac time-of-flight facility. The sample was found to consist of depleted uranium with a ^{235}U composition of 0.15 percent.

IV. Neutron Dosimetry Group

This group is engaged in the development and application of standard and reference neutron fields as permanent facilities for neutron dosimetry standardization, for neutron detector calibrations, and for reaction rate cross section measurements. Strong interactions with outside organizations, both in the federal and private sector, are important programmatic characteristics.

Neutron Personnel Dosimetry (R. B. Schwartz)

Remmeter calibrations were carried out at the Cf Irradiation Facility for a dozen or more organizations in the public and private sector including nuclear utilities and three branches of the military.

The reactor filtered beams at 24 keV and 144 keV were used to test a new concept in remmeter design, developed at the Los Alamos National Laboratory. The new design is based on a two-inch diameter tissue equivalent proportional counter with an attached package of appropriate electronics. Calculations and preliminary measurements at Los Alamos indicated that this hand held instrument should be accurate to within ± 20 percent, as opposed to a factor of two (or more!) for conventional remmeters. In addition, the new instrument is smaller and less costly. NBS provided Los Alamos scientists with a needed measurement in the 20- to 30-keV region to check a calculated cut-off in response. The 24-keV beam is ideal for this response check. The results were more than satisfactory: our calibration agreed with design calculation to within 2 percent. The Los Alamos scientists, encouraged by these results, will proceed to have the instrument developed commercially.

A new line of research consists of measurements with a "tissue-equivalent proportional counter." This is a counter whose gas filling has approximately the same chemical constituents as biological tissue. By filling the counter to an appropriate pressure, the counter will simulate a tissue sphere about one micron in diameter. The spectra, when appropriately analyzed, can be used to determine dose and dose equivalent as a function of the energy deposited in tissue.

In the Technical Activities report last year, preliminary measurements made at the 144 keV beam were discussed. These measurements have been repeated with lower noise electronics and in addition new measurements were made at the 24 and the 2 keV beams. The 144 keV results are in good agreement with calculated spectra, and with other measurements. The 2 and 24 keV measurements are internally consistent, but there are no other results with which to compare.

Computer programs have been written in BASIC for these analyses. In previous measurements of the ^{252}Cf microdosimetric spectrum, electronic noise was a limitation at lineal energies below about 1 keV/μm. By increasing gas gain in the proportional counter and making appropriate changes in the electronics, the lower limit has been reduced to about 0.15 keV/μm.

The neutron dosimetry support program with the Armed Forces Radiobiological Research Institute continues in high gear. Highlights of this effort include: (1) on site measurements in the TRIGA reactor exposure room which led to a decision to replace tissue equivalent ion chambers with NBS-type double fission chambers as the primary irradiation monitor; (2) final design of a neutron check source is finished and fabrication at Reactor Experiments, Inc. has begun; (3) long-standing "polarity effects" (i.e. ion chamber currents dependent upon high-voltage polarity) have been reduced by a factor of five by changing cable type, length and routing; and (4) activation detector measurements in the TRIGA exposure room established spatial gradients and room return for low and high energy neutrons.

In support of the AFRRI integral dosimetry measurements, and of general interest for dosimetry standardization, an effort continues to establish a dosimetry analysis scheme which performs few-group spectrum adjustments of integral detector data by minimizing the sum of squares of differences between observed and calculated detector reaction probabilities. The resulting SPAD analysis code provides a basis for obtaining neutron exposure parameters (e.g. fluence or kerma) from individual integral detector respones without arbitrary spectrum interpolation. The analysis allows major and minor error sources to be distinguished and propagated. The procedures has been applied to activation detector data obtained by a dosimetry lab under contract to AFRRI.

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Dosimetry for Materials Performance Assessment (E. D. McGarry & J. A. Grundl)

As reported last year, the main focus of materials performance dosimetry is associated with the preparation and evaluation of documentation describing reactor pressure vessel (RPV) mock-up experiments at ORNL. Experimental characterization of these neutron fields rests largely upon neutron reaction probability measurements that were referenced to the fission neutron standard fields at NBS.

More emphasis is now being placed on the industry option of making pressure vessel surveillance dosimetry measurements outside rather than inside of the vessels of commerical power reactors. The following paragraphs identify the most significant efforts and related NBS involvements carried out under contract with the Nuclear Regulatory Commission (NRC). The main objective of the NBS effort has been to achieve benchmark referencing of dosimetry measurements through the distribution of Certified Fluence Standards. These standards are threshold and fission-type neutron sensors irradiated in a standard neutron field to a well-defined neutron fluence.

Special ex-vessel (cavity) dosimetry was installed in the Maine Yankee Reactor for the first low-leakage fuel cycle. This dosimetry has been removed for analyses by Westinghouse Nuclear Technology Division (WNTD) and by Combustion Engineering (CE). NBS personnel were on site as consultants to the Maine Yankee Atomic Power Company during the removal and shipment of the neutron dosimeters and have, subsequently, distributed certified fluence standards to benchmark reference the radioactivity counting of the dosimeters. The fluence standards were prepared in the NBS Standard ^{235}U Fission Neutron Field.

Very similar measurements, and NBS participation, are continuing in the H.B. Robinson Reactor operated by the Carolina Power and Light Company.

Cavity dosimetry research has been going on for several years in the Arkansas Nuclear One, Units I and II Reactors and in the McGuire I Reactor with NRC and Electric Power Research Institute (EPRI) support. NBS has supplied certified fluence standards for radiometric counter calibrations, and special paired uranium detectors for measurement of the fast neutron fluences in a number of the experiments. A total of 56 such fluence standards have been distributed, to date.

Florida Power and Light Company is now responsible for coordination of the WNTD, NRC and NBS activities involved with cavity dosimetry for the Turkey Point 3 Reactor. Therein, the NBS paired uranium detectors and other radiometric dosimeters are employed to validate the use of solid state track recorders (recording fission tracks in mica as a means of fast

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neutron dosimetry) in commercial reactor cavities. Finally, Babcock and Wilcox, has separately announced plans recently for a major benchmark experiment to validate SSTR dosimetry in the Davis Bessie Reactor starting in FY 86. Dosimetry standardization via NBS will be part of this program.

Integral Cross Section Measurements (D. M. Gilliam & G. P. Lamaze)

A number of integral reaction rate cross sections were reported out in FY-85. In addition, the unusually large discrepancy between observed and predicted helium production cross sections were examined for a number of reactor physics benchmarks.

(1) In the Cavity Fission Source Irradiation Facility at the Belgian CEN/ SCK Laboratory, a series of cross section measurements were carried out in which the neutron fluence rate was determined by a transfer measurement from the known fluence rate in the vicinity of a calibrated ^{252}Cf neutron source at NBS. The absolute calibration of the ^{252}Cf neutron source was established by means of a manganese bath intercomparison with the standard neutron source NBS-I. Fission spectrum cross sections have been obtained for fission in ^{238}U, ^{235}U, ^{233}U, ^{239}Pu, ^{240}Pu, ^{237}Np, and ^{232}Th. Also included in the measurements were $^{115}In(n,n')$ and $^{58}Ni(n,p)$ cross sections. The ^{115}In and ^{58}Ni cross sections, which are important for reactor dosimetry standardization disagree with the ENDF/B-V tabulations by about (5.9 ± 2.1) percent and (6.2 ± 2.4) percent, respectively. These discrepancies show the importance of using standard neutron fields as benchmarks for dosimetry measurements when accuracies of < 5 percent are sought. Similarly, the fission cross section ratio for $^{235}U(n,f)$ relative to $^{239}Pu(n,f)$, an important quantity for reactor physics, was measured to an accuracy of ± 1.0 percent at CEN/SCK. The value of this ratio obtained from calculation with ENDF/B-V data differs from the experimental value by 4.5 percent.

(2) The spectrum-integrated helium generation cross sections for ^{6}Li and ^{10}B have been determined for the NBS Intermediate-Energy Standard Neutron Field (ISNF). Helium concentrations were measured by precise high- sensitivity gas-mass spectrometric analysis of vaporized small encapsulated and unencapsulated crystalline samples of natural boron, enriched ^{10}B, and enriched ^{6}LiF. The cross section results are consistent with previously obtained data for other reactor physics benchmarks at LANL (Los Alamos), INEL (Idaho), and SCK/CEN (Belgium). A comparison of the ISNF measurement with cross sections calculated using the ENDF/B-V file show a discrepancy of 10 percent for ^{10}B and 5 percent for ^{6}Li. The total error associated with this extraordinary discrepancy, including the ISNF spectrum uncertainty is ± 3.6 percent for ^{10}B and ± 3.1 percent for ^{6}Li.

Of the ten helium production cross sections for ^{10}B and ^{6}Li reported for five reactor physics benchmarks, ENDF/B-V underpredicts nine of the ten by two to five times the experimental errors. Relevant measurements with enriched boron and lithium samples were performed at four different laboratories over a 10-year period. Helium production was determined at Rockwell International by means of the HAFM method and neutron fluences for the required irradiations were derived from NBS fission chamber measurements. A paper was presented at the Sante Fe Nuclear Data Conference which evaluated these neutron fluence assignments and where necessary adjusted them to be consistent and traceable to the fast-neutron fluence scale associated with the NBS ^{252}Cf Fission Neutron Irradiation Facility. Abridged remarks from the paper regarding these discrepancies between calculation and experiment are as follows:

- The C/E discrepancies in $\sigma(n,He)$ for ^{10}B in five very different reactor physics benchmarks are consistent as well as large: average C/E = 0.88 ± 0.03. This suggests serious errors, in some combination of the He production determination, the neutron fluence assignment, the He production cross section, and/or a common bias in the benchmark spectrum calculations.

- Notable C/E discrepancies exist for other reactions with well-studied cross sections in two of the benchmarks for which neutron transport in uranium is important:

- Neutron transport in ISNF, which does not involve uranium, is largely determined by the kinematics of scattering in carbon, and below 0.1 MeV by neutron absorption in ^{10}B: Much larger uncertainties than can be reasonably assigned to these processes would be required to bring the associated ^{10}B and ^{6}Li reaction cross section errors to within 1 s.d. of the reported C/E ratios.

- If a spectrum error below 0.1 MeV is postulated in ISNF it must be attributed to a ^{10}B cross section error and as such is in a direction that will not allow the calculated integral cross section for $^{10}B(n,He)$ in ISNF to change by more than about 50 percent of any corresponding ^{10}B cross section error.

(3) A long series of experiments in which the absolute fission cross-sections of ^{235}U, ^{238}U and ^{239}Pu for ^{252}Cf spontaneous fission neutrons were determined is complete. The absolute cross section for ^{235}U is the basis for all integral fission cross section measurements in NBS standard neutron fields and is recognized by the CSEWG subcommittee on standards as a basic normalization measurement for the ^{235}U fission cross section. The NBS results contain two notable disagreements with ENDF/B-V, the cross

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section file used for almost all design and operations calculation in nuclear technology: The C/E ratio for ^{238}U is 1.057 ± .017 and for $^{239}Pu/^{235}U$ C/E is 0.964 ± 0.008. Some unique features of the measurement are as follows:

- The ^{252}Cf source employed for the measurements has been calibrated repeatedly (5 times between 1979 and 1984) at the NBS Manganous Sulfate Bath Facility against the National Standard Ra-Be photo-neutron source, NBS-1. The precision of the five measurements as determined by a least-squares fit to a 2.645-year half-life of ^{252}Cf is ± 0.5 percent. The presently assigned neutron emission rate uncertainty of NBS-I is ± 0.85 percent leading to a total ^{252}Cf neutron source strength uncertainty of ± 1.1 percent.

- The measurement of distance between fission chambers placed on opposite sides of the source (10 cm) was performed with a computer controlled digital cathetometer fitted with a piezoelectric sensor which operated to a precision of better than ± 0.003 cm.

- Monte Carlo and analytical calculations provided corrections for neutron scattering in the source capsule, in the fission chambers, its support structure, and in the fissionable deposit backings. Neutron return from the walls and floor of the NBS ^{252}Cf Irradiation Facility were investigated in a separate experiment and published separately.

Neutron Source Strength Calibration Facility (E. D. McGarry)

Five neutron sources were calibrated for outside customers at the Manganous-Sulfate Bath Facility. Together with in-house requirements including the ^{235}U cross section measurements just described, a total of 26 individual neutron source determinations were performed. A report of the international neutron source strength intercomparison described in last years report has been completed by the National Physical Laboratory in England. NBS determinations were inside the uncertainty band of the world average.

The NBS bath facility for neutron source calibration at NBS has been in operation for 20 years. For the last eight years neutron sources with emission rates of up to 10^{10} n/s have been calibrated to an accuracy of approximately 1.2 percent. An upgrading of the facility to provide more efficient operation and improved source handling capabilities is moving ahead full bore.

Improvements in Fluence Measurements in the NBS Cavity Fission Source and Intercalibration with the Belgian Cavity Fission Source (G. P. Lamaze & J. A. Grundl)

International intercalibration of standard neutron fields is important for establishing absolute accuracies of neutron fluences and reaction rates. A fluence transfer via the $^{239}Pu(n,f)$ reaction was made from the ^{252}Cf source at NBS to the Belgian cavity fission source and then back to the NBS cavity fission source. The diameter of the MOL cavity in the BR1 Reactor, Mol, Belgium is larger than that of the NBS cavity, resulting in a smaller correction for reflected neutrons. It also allows a fission chamber to be operated within the source. An earlier independent calibration of the Belgian fission source was confirmed by NBS and the calibration of the U.S. ^{235}U Standard Neutron Field was reconfirmed. This new fluence transfer procedure resulted in an overall reduction in the uncertainties of fission neutron fluence measurements at NBS. All of this work as well as the cross sections described under (1) above was reported at the Fifth ASTM-EURATOM Symposium on Reactor Dosimetry in Geesthacht, Germany (Nov. 1984).

Neutron Driven Gamma Ray Field (J. A. Grundl)

In cooperation with two European laboratories and the Univ. of Virginia, a neutron driven gamma-ray field has been constructed to operate in the NBSR thermal column cavity. The main component of the system is a cadmium cylinder which is exposed to a thermal neutron fluence rate of 3 E 11 n/cm^2s giving rise to a cadmium capture gamma-ray fluence rate of about 2 E 11 photons/cm^2s at the center of the cylinder. This corresponds to a dose rate of close to one megarad/h. The gamma ray field strength is determined by two methods: measurement of activation from gold foils placed on the cadmium surface, and measurement of Cd-115 activity induced in the cadmium cylinder.

The cadmium cylinder can be enclosed in a sheath of lithium-6 loaded glass to determine the background of gamma rays from the core and from neutron capture in the surrounding graphite. An iron cylinder, which fits around the lithium glass, has been constructed as an alternate source of iron capture gamma rays in known geometry.

First application of the neutron driven gamma ray field is a measurement of photofission rates in ^{238}U, ^{232}Th, and ^{237}Np and photon activation rates, in indium. Photofission due to gamma background in the facility is presently estimated to be 7 percent of the primary gammas from the cadmium source.

Smaller Projects. (1) The neutron dosimetry group has assisted physicists from the Quantum Metrology Group and the Los Alamos National Laboratory in setting up a neutron lifetime experiment at the reactor. This experiment

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involves absolute beam intensity measurements based on ^{6}Li total absorption in a detector/calorimeter and in a fission ionization chamber using deposits from the NBS collection of fissionable Isotopes Mass Standards. (2) The Nb(n,n') threshold activation reaction cross section will be measured for ^{235}U fission spectrum neutrons in a cooperative program with Prof. Tom Williamson of the University of Virginia. This experiment will entail an unusually long cavity fission source irradiation with attendant problems of handling hot fission disks. The Nb(n,n') reaction is attractive for dosimetry because of its long half-life (16 y) and low response threshold. Because of the long half-life the energy dependence of the reaction cross section is poorly known and therefore the fission spectrum integrated cross section is especially valuable. (3) The development of a new mega-gray gamma dosimeter was initiated this year. Crystals of ^{7}LiF, originally investigated by CRR's Bill McLaughlin have been exposed to mixed gamma and neutron fields to ascertain their ability to respond selectively to gammas rather than neutrons, an unusual property for any dosimeter. Results are promising, sufficiently so that we have received funding for the "LiF chip" investigation from the Nuclear Power Division of Babcock & Wilcox.

V. Radioactivity Group

Introduction

During this period there has been an emphasis on technique or instrument development within the Group. In two cases the result may be the demonstration of techniques of broad significance for radioactivity measurements; in others the capabilities of Group members have been focused on other-agency problems of immediate concern. Our traditional measurement techniques are also now better instrumented.

A wider distribution of activity calibrations developed at NBS was also achieved, with more traceability exercises testing the measuring ability of key laboratories. A major nuclear pharmacy organization with over 50 distribution centers joined the AIF radiopharmaceutical program. The pertinence of the form of NBS and commercial reference materials to the required measurement of radiopharmaceuticals in injection syringes was investigated. Chemical problems encountered in environmental radioactivity monitoring were probed.

These, and other major activities, are discussed in the sections that follow.

Distribution of Radioactivity Standard Reference Materials (SRMs) and Measurement Services

The following table sumarizes explicit interactions which propagated basic NBS activity calibrations between August 1, 1984 and July 31, 1985.

Radioactivity SRMs distributed	709
SRMs under the AIF program for nuclear medicine	294
Scheduled Calibrations	41
Special Measurements	80
Traceability exercises including EPA, FDA, NRC, and commerical firms	133

The traceability exercises carried out with the regulatory agencies, radiopharmaceutical manufacturers, and suppliers of commerical reference materials test the ability of a laboratory to supply an activity value for a sample of a radionuclide before the NBS calibration is known. The exercises do not, except in special cases or by inference, test or investigate the general quality-control procedures within the laboratory, which would be a much more ambitious undertaking.

Uranium-Analysis Discrepancies in Natural-Matrix SRMs (K. G. W. Inn)

We have been confronted with several radiochemical challenges during the production of environmental-level radioactivity SRMs. Recently we have investigated an apparent discrepancy in the uranium data set from assays of SRM 4353 (Rocky Flats Soil-1) and SRM 4350B (River Sediment). The difference appeared to be on the order of twenty percent between sample pretreatment methods. We have made recent advances in understanding the nature of the chemical problem which was biasing some of the reported data. Some laboratories were requested to perform additional analyses; x-ray diffraction and emission spectrometry were used to assay residual materials after corrosive acid treatment of the sample; and alternative dissolution radiochemical methods were used to evaluate the residual materials for excess uranium. The results appear to support the hypothesis that there is a minor mineral fraction with high specific activity of uranium in these SRMs which resist corrosive acid treatment. We tentatively ascribe the discrepanices in the uranium data set to the inability to equilibrate chemical yield monitors with the samples.

Xenon-Isomer Electron Spectrometer (F. J. Schima, A. T. Hirshfeld, & D. D. Hoppes)

Gamma-ray spectrometry can be used to detect moderately low levels of ^{133}Xe or ^{135}Xe in a gas sample, but the large internal conversion in the decays of ^{131m}Xe and ^{133m}Xe makes this method insensitive for these isomers. In order to select and measure the internal-conversion electrons from these decays, we have constructed trial systems in which xenon is condensed on the surface of two closely spaced 450 mm^2, 500-μ-thick silicon surface-barrier detectors. The large detector areas minimize source scattering, and the proximity of a second detector reduces the effect of backscattering.

The cryostat head fits inside the well of a NaI(Tl) detector. A beta-particle coincidence requirement can be used to greatly reduce the background for the gamma-ray spectrometer measuring the ground-state decays, while an anti-coincidence requirement with all photons above x rays detected in the NaI(Tl) reduces the environmental and beta-spectrum background for the conversion electrons.

Despite these techniques, the electron background remained about 0.05 cs^{-1} in the pertinent energy region in the first two systems constructed. A careful investigation of construction materials with a low-level beta-ray counting system revealed that the mounting rings for the surface-barrier detectors could be making a major contribution. A search for alternate materials led to the use of a special epoxy, and trial detectors constructed with rings prepared here from castings of this epoxy have operated successfully with reduced background.

A cryostat redesign minimizes outgassing, and thermal radiation input. The new system is under construction, and optimal analysis programs are being developed.

Large-Area Source Calibration Technique (J. M. R. Hutchinson)

A program to develop traceability of the U.S. Air Force alpha-particle field measurements has been underway. The USAF uses surface monitors (Radiac Calibrators) which are calibrated with UDM-7 large-area ^{239}Pu sources. Because no existing counters were large enough to measure the UDM-7's, the first year of the project has been devoted to designing and setting up two large area counters - approximately 12-in by 14-in in sensitive area. One of the counters is an internal-source proportional flow counter and the other a similar but external-source counter.

Both counters are adapted from commercial counters of German design. The response as a function of various relevant parameters -- source position, voltage, amplifier gain -- was tested extensively. Values of these parameters were found that would give suitable system characteristics to permit measurement of the UDM-7's to the required accuracy.

The UDM-7's, which are electrically nonconducting, cannot be inserted directly into the internal counter. The calibration procedure makes use of a specially prepared conducting large-area source which is measured in the internal counter. A layer of thin conducting material is then placed over the source, and the change in the count rate recorded. An area of a UDM-7, previously cut to fit the large-area counter, is measured in the internal counter with the conducting layer over it. From this information, the emission rate of the reference piece of the UDM-7 can be determined. Any other UDM-7 can then be compared with this reference source using the external counter.

Experiments With Resonance Ionization Mass Spectrometry (RIMS)
(J. M. R. Hutchinson & K. G. W. Inn)

Last year, NBS embarked on a DoE-supported program to assist in the development of the RIMS technology with the ultimate goal of providing suitable standards which will help to elucidate its role in research and, particularly, industrial applications. There are two components to the effort, (i) use of the Sputter Initiated Resonance Ionization Spectrometer (SIRIS) instrument to improve the SIRIS response, initially to uranium, and to improve the isotope dilution technique, and (ii) production of isotopic ratio standards, initially $^{10}Be/^{9}Be$. With regard to this latter effort, plans are under way to mount a seven laboratory collaboration including the NBS Mass Spectrometry Group.

With regard to the first, two more working visits were made to Atom Sciences in Oak Ridge, the developer of this revolutionary instrument used in ultrasensitive analysis. Sources were prepared at NBS to test, and help improve, a number of characteristics of this instrument. Overall, the conclusions reached from these visits were as follows:

Visit #I

1. The attachment of oxygen to uranium presents a major problem in sensitivity for that element. The solution of this problem is of major importance to this program.

2. At this time, the most promising method for calibrating the system is by means of isotope dilution. The relationship of the SIRIS response to a standard of one material and an unknown of another is not clear for several reasons which include different neutrals-to-argon-ion production, different angular and energy distribution of neutrals, different amounts of quenching due to oxygenation of the surface, physical differences in the surface, chemical and physical effects of constituents in the sample other than the one of interest, and reproducibility of the current density and indeed of the system from sample-to-sample.

Division 536, Technical Activities (cont'd.)

3. The homogeneity of the samples at the microscopic level appears to be satisfactory for the sample that was investigated. This implies that the graphite was adequately mixed with the sample.

4. Results of the source conductivity tests were inconclusive but there was an indication that the signal was reduced by at least a factor of two for nonconducting sources containing only KBr as a binder relative to conducting sources containing graphite.

5. Comparison of SIRIS responses for vanadium concentrated in the various soils and sediments gave generally expected results. However, before a meaningful interpretation can be obtained, the factors listed in item 2 (above) would have to be quantified.

6. The data support the picture that neutral uranium atoms are emitted copiously from metallic uranium, only uranium ions or ionic forms of uranium oxide are emitted from surfaces which are oxidized (such as the natural materials), yet vanadium neutrals are emitted in large amounts from natural materials (which presumably contain vanadium oxide). Therefore, to obtain a significant SIRIS uranium signal from a natural material, ionic uranium must be reduced either within the source or in an intense plasma created during the sputtering process. It appears to be not necessary to make this heroic effort for vanadium.

Visit #II

7. There is a large, unexplained improvement (factor of 5 to 26) in the uranium response of the spiked, unfired graphite sample over all the other samples. This difference is seen even over the unfired spiked soil.

8. Examination of the results of the spiked graphite and soil which contain ^{235}U and ^{238}U in the same chemical form, shows that instrumental uncertainties are in the few percent range at most.

9. No great effect was observed in the ratios of the responses due to firing of the samples. By and large, firing seems to reduce the response for a given isotope by at the most 30 percent.

10. Overall errors in the observed isotopic ratios due to isotope dilution are only on the order of a factor of two or less, including machine-, chemical-, and physical-based uncertainties. Further investigations could very well lead to methods for improving this situation considerably. For example, etching the phosphate ore samples with the d.c. beam for longer period to be sure that the insides of the particulates are being sampled may improve the response.

Progress With Radon-in-Water and Radon Flux Standards
(J. M. R. Hutchinson and R. Collé)

The Environmental Protection Agency (EPA) has supported efforts related to the monitoring of radon in the environment. This program represents a collaboration between the Office of Radiation Measurement, CRR and the Radioactivity Group.

The radon-in-water standard is concerned with the correct measurement of gaseous, potentially harmful radon in drinking water. During this year, an instrument which delivered an accurately known activity of radon in an accurately known volume of water was completed and sent to the EPA laboratory at Las Vegas where it is in daily use.

A second radon standard, which is under development, aims to provide an accurately calibrated radon flux from a surface large enough to calibrate commerical radon-monitoring equipment. The program for the development of this standard has proceeded in four stages (i) development of a gas-handling system which can be used to sample the radon flux from the standard and enable the sample to be measured in the NBS pulse-ionization chamber; (ii) proving the principle of the standard; (iii) construction of the standard, including design of a configuration for the measurement of the flux; and (iv) measurement of the flux. The first three stages are essentially complete and the fourth stage is beginning.

Measurements with High-Efficiency NaI(Tl) Detection Systems (C. Ballaux)

A guest worker from the Studiecentrum voor Kernenergie, Mol, Belgium used one of the group's high-efficiency scintillation-detector systems to check a ^{133}Ba basic activity calibration previously established with a pressurized proportional counter anticoincidence system, and another to check previous direct gamma-ray-emission-rate measurements of ^{109}Cd.

The analysis of measurements of ^{133}Ba sources between two 8" by 4" NaI(Tl) well-crystals uses a calculated efficiency based on a measured efficiency vs energy relation and a known decay scheme. The calculated probability of not detecting any radiation from a complex decay (here about 3 percent) is not sensitive to branchings or internal conversion coefficients if the detector efficiency is high for all radiations. The ^{133}Ba result agreed with the previous value to about 0.3 percent.

The measurement of the 88-keV gamma ray of ^{109}Cd with small-diameter-well 2" by 2" NaI(Tl) detectors involves several small corrections to the calculated total efficiency. A re-evaluation of these corrections led to an emission-rate value differing from the previous measurement by about 0.8 percent.

Gas Counting (F. J. Schima and M. P. Unterweger)

This year two samples of hydrogen-tritium (HT) gas have been calibrated in the length-compensated gas-proportional counting system. The first sample, from W. R. Miller of the Gas and Particulate Science Division (NBS), contained enough gas for us to accurately measure a known gram-mole amount. A specific activity of 1.075×10^6 Bq/liter was determined with an overall uncertainty of 3.1 percent. The random error for five measurements was 0.14 percent. The second sample, from LMRI, was counted totally, as the quantity of HT gas was too small for an accurate gram-mole determination. The result for LMRI ampoule #1 was 1.086×10^4 Bq with an overall uncertainty of 3.4 percent and the random uncertainty for six measurements was 0.14 percent.

In addition to these activity determinations, a detailed study of the beta spectrum from the tritium decay is in progress. The ultimate goal of this study is a comparison with theoretical spectra for the energy region from 50 to 18400 eV to check if tritium beta decay is consistent with the emission of a single neutrino of nearly zero mass.

Gamma-Ray Spectroscopy (F. J. Schima)

Successive-approximation analog-to-digital converter systems made by EG&G Ortec, Inc. have taken over most of the pulse-height data-acquisition duties in the Radioactivity Group. Three of these units, known as ADCAM's, are now used to acquire data from the five main semiconductor detectors. An unsuccessful effort was made to use an ADCAM in a multiplexed mode. Most of the software that had been used to process data obtained with the previous PACE system has been successfully transcribed to operate the ADCAMs and process data. Additionally, an automatic peak fitting program has been developed which samples the channel contents above and below the peak distribution for a background estimate. Procedures are under development to incorporate measurement results automatically into our existing efficiency-function data base.

Computer System (M. P. Unterweger)

The Charles River Data System has had the number of user ports increased by eight to a total of twenty ports. The system still supports typically only five terminals which serve the staff computational and data-reduction needs. However, the increase in user ports allows for the direct service of all the Group's present data-acquisition systems such as those for the liquid-scintillation counters. Control and processing procedures for the latter have been implemented on the Charles River System. In fact, all of the data acquisition programs supported by the Data General Nova have been transferred to the Charles River System. The half-life data files, however, remain on the Nova.

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An 8-bit microcomputer obtained as surplus has been put into operation for handling data-based files and programs related to the SRM and calibration services. These include mail lists, form letters, and shipping forms. A new IBM Quietwriter printer has been installed and used with Wordstar and DBASE II programs.

Computer-Controlled Dispenser For Preparing Radioactive Sources
(L. L. Lucas)

As part of the "cross-check" program carried out by the Environmental Protection Agency (EPA) for the Nuclear Regulatory Commission (NRC) under an interagency agreement, identical samples of radioactive materials are supplied to participating commercial, educational, governmental, and other laboratories for analysis as unknowns. The results, reported to EPA and tabulated by them, serve as a "cross-check" of the accuracy and reproducibility of individual laboratory measurements. This helps to identify and correct measurement problems and to improve measurement assurance.

One common type of radioactive material used in the program consists of a piece of filter paper impregnated with one or more radionuclides. These spiked filter-paper sources, which are produced in several sizes and in quantities of up to several hundred at a time, are used to simulate filter-paper sources from air samplers. Air samplers are extensively used to monitor exhaust gases and the general environment for radioactive particulates.

The production of large quantities of identical spiked-filter-paper sources requires accurate, repetitive dispensing of radioactive solution in a carefully-controlled pattern and sequence -- an ideal task for a computer-controlled dispenser. Under contract to NRC, the Radioactivity Group is producing such a dispenser. Several features of the device that are considered essential for its intended use are:

(1) Modularity

High-quality, commercially-available components are used whenever possible to make repair, replacement, and replication as simple as possible. The interfaces to the dispenser and positioner mechanisms are RS-232C so that the operation can be controlled by virtually any computer at any distance.

(2) Resistance to corrosion and contamination

All of the components in contact with the radioactive solution (tubing, valve, and syringe) can be removed without contaminating the rest of the system. The dispenser and positioner mechanisms can be isolated from the work area to avoid corrosion (the radioactive solution is often strongly acidic and emits acid fumes as it dries).

(3) Simple control

The dispensing and positioning mechanisms are controlled by simple sequences of ASCII characters. Each mechanism provides verification that a command has been received and carried out. This greatly simplifies the computer programming.

The unit is expected to be operational in early FY 1986 and to be producing spiked filter-paper sources a few months thereafter.

SRM's Delivered (B. M. Coursey)

During the year August 1984 through July 1985 nineteen radionuclides were distributed as radioactivity Standard Reference Materials. These included x- and gamma-ray SRM's for photon detector calibrations: ^{55}Fe, ^{57}Co and long lived mixed (^{125}Sb, ^{154}Eu, ^{155}Eu) solutions. Four high-Z nuclides were distributed for use in traceability tests: ^{208}Po, ^{229}Th, ^{243}Cm and ^{226}Ra. The NBS high level ^{3}H-water standard (SRM 4927C) was also reissued. The radiopharmaceutical SRM program resulted in the distribution of the following ten short half-life radionuclides: ^{111}In, ^{99m}Tc, ^{32}P, ^{203}Pb, ^{131}I, ^{99}Mo, ^{67}Ga, ^{133}Xe, ^{201}Tl, and ^{51}Cr.

FDA ^{99m}Tc Clinical Measurements Check (B. M. Coursey, J. M. Calhoun, D. Golas)

The USFDA enlisted the support of NBS in a nuclear-medicine quality-assurance program with a commerical supplier of ^{99m}Tc radiopharmaceuticals. SYNCOR, which operates 36 regional distribution facilities, agreed to furnish calibrated syringes of ^{99m}Tc to their customers and to collect their results and provide them to the College of American Pathologists (CAP) for evaluation. NBS provided calibration services to the SYNCOR corporate laboratory and measured standard syringes submitted by nine of the regional facilities.

Liquid-scintillation Counting (B. M. Coursey)

This was the first year of a 5-year cooperative program with the Junta de Energia Nuclear on the development of liquid-scintillation techniques in radionuclide metrology. The first year objective was the standardization of pure beta-particle emitters. Standards were developed for ^{63}Ni, ^{241}Pu, ^{14}C, and ^{90}Y, which cover a beta-particle energy range from 20.8 to 2283 keV. The overall uncertainties in these standards are of the order of 1 percent.

Computation of counting efficiencies were continued on the JEN UNIVAC and at the NBS UNIVAC on the three programs: EFFY (pure beta emitters), VIAS (electron-capture emitters) and GAMMAS (a Monte Carlo code for photon interactions). In addition, measurements were made to compare with computer calculations for three simple EC radionuclides: ^{55}Fe, ^{54}Mn and ^{51}Cr and one internal transition nuclide ^{99m}Tc.

Liquid scintillation techniques were developed for the measurement of low-level tritium in water samples. These samples were prepared by quantitative combustion of tritiated methane and tritium in hydrogen gas. The liquid scintillation results were used to assign activity concentration values to the original gaseous samples.

Container Dependence In Dose-Calibrator Measurements (J. M. Calhoun, D. Golas)

The commerical dose calibrators used for checking the activity of radiopharmaceuticals in syringes before injection are calibrated with solutions in 5-mL NBS ampoules. Commercial reference materials are usually supplied cast in epoxy in plastic bottles. However, sample position, sample volume, and container type may be significant in dose calibrator measurements. In order to check for possible errors of this type, comparative measurements of two radionuclides in different volumes in three containers were made.

A joint project between NBS and duPont/NEN, a producer of radiopharmaceuticals and reference sources, compared the indicated activity of ^{57}Co samples in NBS 5-mL ampoules, syringes, and NEN Vial "E" epoxy- and solution-filled bottles, and ^{99m}Tc solutions in NBS 5-mL ampoules, NEN Vial "E" bottles, elution vials, and syringes. The measurements were made in typical dose calibrators obtained from two different manufacturers, Capintec and Radcal. The main objective of the project was to examine the use of the NEN Vial "E" as a suitable reference source for dose calibrators, and assay ^{99m}Tc in elution vials and syringes.

Measurements were performed at NBS and at duPont/NEN. Several conclusions could be drawn from the observations. All the calibrators gave results within two percent of the NBS activity in all cases where measurements were made in NBS ampoules. Sources in epoxy gave a higher response than NBS ampoules because of the lower density and other geometry considerations. Vial "E" bottles never showed greater than four percent difference from the NBS value in either solution or epoxy. All syringes showed decreasing response with increasing volume of solution or epoxy, with ^{57}Co. The brand of syringe used had little significance on the results. Each manufacturer's calibrator showed varying deviations from the NBS value in different geometries due to differences inherent in the design of each chamber or sample holder, or where the NBS ampoule was positioned when the instrument was originally calibrated. The Radcal calibrator showed the largest deviations with syringes suspended from the sample holder. The Capintec calibrator showed the largest deviations with elution vials at low volumes.

The exercise illustrated that regardless of the brand of dose calibrator used, a calibration factor for each geometry should be determined to ensure the highest accuracy. The data show that as much as a nine

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percent difference from the correct activity can be recorded in certain situations, even when the ampoule reference source is giving the correct answer. Variations are also dependent on the radionuclide. These results will be published.

Handbook of Radioactivity Measurements Procedures Published (W. B. Mann)

The National Council on Radiation Protection and Measurements recently published a revised edition of NCRP Report No. 58, A Handbook of Radioactivity Measurements Procedures, edited by Wilfrid B. Mann, former NBS section chief and group leader for Radioactivity, and present guest worker. The first edition of this work, published in 1978, has been accepted as a definitive reference in the metrology of radionuclides.

The 1985 edition features new material on liquid-scintillation counting, including techniques under development at NBS in cooperation with the Junta de Energia Nuclear of Spain, and an added section on uncertainty statements and traceability methods for radioactivity calibrations. An appendix of over 150 pages lists pertinent nuclear decay data for significant radionuclides.

VI. X-ray Physics Group

High Intensity Gamma-Ray Dosimetry (J. C. Humphreys & W. L. McLaughlin)

The amount of high-dose calibration and test service work performed for industrial radiation processing customers has continued to expand, following the trend of recent years. The total number of calibrations performed was approximately 100 with a subsequent fee income of about $100k. This is an increase in fee income of about 40 percent over last year. The calibration technician added to the staff last year has enabled the staff to handle this increased calibration service business by greatly improving the efficiency of operation. That has subsequently reduced significantly our turnaround time for these calibrations. Other improvements to the calibration service include the automation of data acquisition from the spectrophotometer dosimeter analysis equipment. Microcomputers and other dedicated data acquisition equipment have been acquired and will enable the staff to complete the automation of all data handling and processing in the near future, including final calibration report generation. In addition, the new high dose-rate Gammacell ^{60}Co irradiator acquired last year is being fitted with a gas cooling system for the irradiation chamber to allow irradiation of temperature sensitive dosimeters and samples. This will enable the staff to perform a high-accuracy calibration of the dose rate and thus allow this irradiator to be put on line in the dosimeter calibration service. Use of the Gammacell should increase the throughput for the service by at least a factor of two.

Another improvement to the calibration service was the addition of a humidifier to the air conditioning system of the laboratory used for the handling and irradiation of all dosimeters. This will provide the proper environmental conditioning for the humidity-sensitive dosimeters during the winter months and avoid any interruption in performing calibration services. Efforts continue on developing criteria for the acceptable performance of secondary dosimetry calibration laboratories.

Standards committee work continues to play an important role in the development of radiation processing technology. NBS staff have been the principal authors of several new draft standards within ASTM subcommittee E107.07. A number of these standards deal with food irradiation dosimetry. Since the food irradiation industry appears to be on the potential threshold of rapid (perhaps explosive) expansion, it is very important that adequate dosimetery techniques and methods be available to this industry at this time. Participation continues in the Association for Advancement of Medical Instrumentation dosimetry task group including the round-robin dosimetry intercomparison of ^{60}Co facilities at NBS and seven industrial medical product sterilization plants in Canada and the U.S. Work has been initiated in that task group to develop new electron dosimetry standards since there is increasing interest within the industry in utilizing the new generation high-power accelerators now available for radiation processing.

Development of the prototype liquid-core optical waveguide dosimeter for personnel use continues. Some of the new results include the measurement of the temperature dependence of the absorbed dose response, improved reproducibility in the fabrication of the wave guide, improved techniques in reproducible optical alignment for spectrophotometric analysis and measurement of dosimetric sensitivity in both gamma and neutron fields. Another important development was the use of the optical waveguide as a real-time dosimeter. This application of the dosimeter promises to have exciting potential uses in such areas as in situ medical diagnostics. The basic design uses a light source such as a laser or light emitting diode to illuminate one end of the coiled wave guide and a photodiode detector at the other end. Measurements have been made on the reproduciblity of the dose response on the dose rate dependence, on the effect of optical path length, on the effect of the coil radius, on the effect of the illuminating light wavelength, and on the intercomparison with spectrophotometric type of analysis.

International standards activities in high-dose dosimetry included several important functions. The Report to the International Commision on Radiation Measurement and Units entitled "Dosimetry for Radiation Processing" from the Committee chaired by W. L. McLaughlin was formally submitted to the Commission in 1985. A new Advisory Group on High-Dose Measurements of Electron Beams for Radiation Processing was formed in 1985 by International Atomic Energy Agency, with McLaughlin as a charter

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member. McLaughlin and Humphreys participated in a three-nation (US, UK and Denmark) absorbed dose intercomparison of graphite calorimeters for high-dose standardization. Arne Miller from the Riso/National Laboratory of Denmark spent five weeks as a guest worker at NBS in late 1984 assisting in the development of these calorimeters as new national primary standards of absorbed dose at high doses. Initial plans were also made with the Gesellschaft für Strahlen-und Umweltforschung of the Federal Republic of Germany for them to be included in future standardization intercomparisons with NBS.

Dental Fluoroscopy and Tomography (J. W. Motz & J. H. Sparrow)

In collaboration with the National Institute of Dental Research, the X-ray Physics Group is developing a dental tomographic system which will have the capability of producing dental images at different depths in any given tooth. The system requires the development of a special x-ray tube, intra-oral image detector, and image processing system which can provide and process several dental images in less than a second. Each of these components has been designed and is curently in process of construction, with the expectation that tomographic images will be produced in FY 86.

At the request of the Army Institute of Dental Research, the X-ray Physics Group has developed a hand-held dental fluoroscopic system which has the potential for order of magnitude lower x-ray exposure than that required with dental film and which has the capability of image storage and retrieval on a floppy disc. This system is presently under test and will require further development for the specific needs of standardization in army field operations.

Performance Evaluation of DOD High Energy Radiological Inspection Systems (D. Polansky)

At the request of the Navy Department, this program carries out the following tasks:

1. Establish a measurement procedure such that facilities performing high energy radiological inspection on missiles can calibrate the x-ray output of the linear accelerators they are using. Until such time as the facilities have on hand the calibrated equipment and trained personnel to perform the measurements, NBS staff members will continue to provide these services every 12 to 18 months.

2. Perform an on-site audit of the radiological image quality achieved at the various DOD facilities and at the various DOD product manufacturer; participate in the new design of a test specimen used to evaluate both image quality and system performance for CT systems used in the radiological inspection of missile propulsion units and gas generators.

3. Assist in the integration of old and new radiological inspection methods (film, real time and tomography) to assure that there is a consistency in the quality of inspection so that data from different inspections can be correlated.

Nondestructive Testing of Very Thick Walled Castings (R. C. Placious)

At the request of Sandia Laboratories, NBS was asked to survey the present state of the art in nondestructive inspection of very thick-walled (12"-15") ferrous metal casks. This is a team effort in which the X-Ray Physics Group participates in the radiological aspects of the program.

The primary material of interest here is a relatively recent development so that the technical base for fabrication and inspection is still maturing. To the extent possible, the quality of inspection presently achievable with similar, but not identical, materials will be evaluated. We are also asked to evaluate the quality of inspection that may be achievable as a result of newer, emerging radiological methods and to recommend the specific NDT technologies that should be pursued for inspecting huge monolithic steel/cast iron castings.

Standard Visual Test Patterns for Radiographic Interpreters (R. C. Placious)

Field testing of the first set of slit images indicated that skilled readers could score better than 90 percent without adhering to the test protocol. We are modifying some of the slit patterns to increase the difficulty of detecting some of the patterns. The new test set will be distributed to several laboratories for evaluation.

Radiographic Image Quality Standards (R. C. Placious)

Present work on a method of image quality evaluation is directed at the very high (5-15 MeV) and the very low (10-50 keV) x-ray energies. Consideration is being given to a redesign of image quality indicators especially at the high x-ray energies. Cooperative work with industry members of the nondestructive testing committee in ASTM is continuing on this task.

Accelerator Radiation Sources (C. E. Dick)

The X-ray Physics Group operates, maintains and uses three electron accelerators for the production of electron and photon beams. These sources are used for a variety of programs related to dosimetry, pulsed radiolysis, medical and industrial radiography, and basic measurements. In the past year, utilization of these sources has increased with the continuation of ongoing programs and the utilization of these sources by

various groups outside of NBS. In the following, the operating parameters and current status of each of these accelerators is described along with a brief description of the research activities currently under way.

(A) 500-keV Constant Potential Accelerator (C. E. Dick)

The 500-keV cascaded rectifier accelerator has been in use for over 30 years as a low energy electron and photon source. This machine continues to be one of the most reliable pieces of apparatus in the group. The electron energy is continuously variable from 0.01- to 0.5-MeV with beam currents from 10^{-9}- to 10^{-4}-Ampere. The accelerator is equipped with a scattering chamber for differential angular measurements from 0- to 175-degrees, or the electron beam can be deflected to provide a horizontal beam for other experiments. Currently, the accelerator is being utilized for the following experiments:

- The production of standard electron beams for the calibration of instruments used for beta-ray dosimetry. Work is currently under way to determine the energy spectra and fluence of these beams which are brought out of the high-vacuum of the accelerator through a thin window into the air.

- A collaborative effort is underway to investigate possible coherence effects in the production of Cerenkov radiation. The optical spectra of the radiation emitted by this process is currently being investigated by a group from Howard University.

- The electron beam from this accelerator has been used to produce monoenergetic-photon beams in the region from 10- to 70- keV. These beams will be used by a guest worker from France to investigate the properties of halogenated and rare-earth compounds used as contrast media in medical radiography.

(B) 1.5 MeV Dynamitron (C. E. Dick)

The 1.5 MeV dynamitron is an extremely stable source of electrons in the energy range from 0.2 to 1.25-MeV. The vertical beam from this accelerator is deflected horizontally by a magnetic field and can be directed into either of two scattering chambers. Beam currents range from 10^{-9}- to 10^{-3}-Ampere. Currently this source is being utilized in the following efforts.

- Measurement of photon spectra produced by variations in the electron energy, target material, observation angle, and beam filtration. These measurements are designed to produce quasi-monoenergetic photon beams in the region from 0.1- to 1.0- MeV for digital subtraction imaging and industrial radiography studies.

- An experimental setup has been constructed to utilize high intensity monoenergetic photon beams in the sub 100-keV regime to investigate the effects of electron binding on the Compton scattering process for photons.

(C) Electron Van de Graaff (C. E. Dick)

The 4-MeV Van de Graaff electron accelerator has been in use for over 15 years as a source of high energy electrons and photons for Division programs in atomic and molecular physics, nuclear physics, dosimetry, and the production of standard radiation fields for instrument calibration. This accelerator has been extensively modified to enable the production of pulsed electron bunches to be used in experiments in pulsed radiolysis and chemical kinetics. At present, the accelerator is capable of producing pulsed electron beams with 6 fixed pulse widths between approximately 5 nanoseconds and 5 microseconds with beam currents of up to 0.5 amperes in the pulse. In the present configuration, these beams are available at energies from 1.2- to 2.75- MeV at an experimental location directly below the accelerator structure. Work is under way to provide the capability to deflect these beams into a larger experimental area without significant loss in beam quality, and to extend the maximum energy above 3 MeV. These additional capabilities will require extensive modifications to the electron gun assembly and beam-handling optics. The accelerator is also capable of producing dc beams from 10^{-9}- to 10^{-4}-Amperes at five horizontal locations. Present uses include:

- The generation of electron beams of known energy and fluence for the calibration of instruments used in beta-ray dosimetry. These beams have been used by groups from Los Alamos and Idaho Falls for the calibration and characterization of instruments under development.

- An effort to investigate the presence of coherence effects in the processes of transition radiation and the Smith-Purcell effect as electrons interact with periodic structures. This program is being carried out with a group from the Lawrence Livermore National Laboratory.

- Measurements have been made on the pulsed electron beam at the straight-through beam position to determine the suitability of the beam for pulsed radiolysis. These measurements indicate that the beam in this position is quite usable for these measurements. In addition, preliminary designs for a non-dispersive magnetic deflection and focusing system have been considered in order to provide the same quality beam at two horizontal beam locations.

Digital Energy Subtraction Imaging For Biomaterials (C. E. Dick)

A program has been initiated to investigate the application of digital energy subtraction to the imaging of biomaterials used in medical applications. In this technique, the differential absorption of different energy photons is utilized to provide a difference signal between the structure of interest and the surrounding medium. Previously, we have developed the basic methodology to produce quasi-monoenergetic photon beams by filtration of spectra produced by conventional x-ray machines. Presently, experiments are under way to provide subtraction of various structures approximating those found in medical radiology. In addition, a computer algorithm has been developed to predict the shape of these filtered spectra from a set of baseline spectra. This computer algorithm generates a reasonable approximation of the effects of various filters without the necessity to make tedious measurements for all materials.

In order to examine the energy subtraction technique, we have assembled a real time imaging system with image processing capabilities. This system consists of a 23-cm diameter image intensifier tube whose output is viewed by a television camera. The analog output of the camera is digitized and stored by a computer-based image processing system. In the last few months, extensive renovations and testing of this system has been under way and it is now ready for the recording of images. In addition, the procurement of a medical phantom designed for the evaluation of images generated in Digital Subtraction Angiography (DSA) has been initiated. This phantom will allow the investigation of geometries and materials encountered in medical radiography.

VII. Electron and Photon Dosimetry Group

Use of ionizing radiation is becoming ever more widespread in modern society. The exposure of humans can be purposive (medical) or incidental (occupational), but both require close control to ensure that the radiation is efficacious in the one case, and harmless in the other. Such control can only be achieved with reliable measurement. With the increased use and the improved knowledge of radiation effects, the need for more accurate measurement is constantly increasing. The measurement of ionizing radiation for the purpose of controlling a radiation effect falls in the field of radiation dosimetry. The Electron and Photon Dosimetry Group has the responsibility for providing an up-to-date basis for reliable measurement of ionizing radiation, principally in medicine and radiation protection. This program involves: (1) establishment and maintenance of the national primary dosimetry standards; (2) dissemination of the units established by those standards by means of calibration services and measurement quality assurance programs; (3) research and development of measurement technology as necessary for any part of the program; and (4) participation in the relevant national and international activities of the community of radiation users.

X-ray and γ-ray Calibration and Measurement Assurance Services
(J. T. Weaver & P. J. Lamperti)

Calibration services for x-ray and γ-ray measuring instruments have continued to increase in efficiency, aided considerably by the addition of a junior technician in May 1985. The reimbursable income for the 350 tests performed was $140,000. Principal users were medical institutions and nuclear power establishments.

The operating system for the dedicated DEC 1123 minicomputer was updated from the RT11 version 4 to version 5.1, to permit transfer of the files over the NBS Net to the new NBS Cyber 855 computer. The main calibration program, written over a period of ten years in Fortran 66 (UNIVAC Fortran V), was converted to Fortran 77 for the UNIVAC 1100/82 computer, and then adapted for the Cyber 855.

Measurement assurance tests have been carried out with the five AAPM therapy-level accredited calibration laboratories of the AAPM, and to five protection-level laboratories. As usual the test equipment was shipped around to all the laboratories before return to NBS, using the check methods devised for the particular equipment being used. Traceability to NBS is maintained by the measurement assurance test, without recalibration of the local standard chamber, unless the test shows it to be necessary.

The Navy thermoluminescence dosimetry (TLD) measurement assurance program continues. The program is sponsored by the Naval Electronics System Command, and involves preparation by NBS of boxes of 15 TL dosimeters, 12 of which have been given known exposures to ^{137}Cs gamma rays. The boxes are dispatched to designated Naval units for readout, the results of which are returned to NBS for comparison with the NBS exposures. TL readers that indicate exposures differing from the NBS exposure by more than ±13 percent are repaired and recalibrated. About 275 such boxes, containing 3300 exposed dosimeters, were dispatched during FY85.

Complete documentation of NBS photon dosimetry standards and calibration techniques was prepared by T.P. Loftus, under a 6-months contract. Loftus, who retired in June 1984, had more than 30 years' experience with NBS calibration procedures, and was in a unique position to carry out this task. The material will be edited for publication as an NBS Internal Report.

High Energy Electron and Photon Measurement Assurance Services
(C. G. Soares)

There were four mailings of Fricke dosimeters in FY85, involving 62 sets of participants, engaged primarily in radiation therapy. Two batches of dosimeters were prepared. In principle, each dosimeter can be used as many times as it takes to accumulate 200 to 300 Gy. In order to conserve

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time, and thus cost to the participants, the tests are administered simultaneously to as many participants as the batch size permits. In order to handle the increase in volume that the service has experienced in the last few years, 60 new cells have been ordered, which will allow an increase in the number of cells per mailing, and possibly a decrease in the number of mailings. We are investigating a change to a system using inexpensive sealed vials instead of spectrophotometer cells. This should reduce the variability of response changes with time, resulting in improved accuracy and sensitivity. It is planned to augment the chemical dosimetry service with a TLD service, if technical problems connected with the required extensive automation can be solved.

Standard Monoenergetic Electron Beams (C. G. Soares)

Work continued on the development and characterization of monoenergetic electron beams for the calibration of instruments used primarily in radiation protection. Spectral measurements of the electron beams were extended to 2.5 MeV with the 6.3-mm thick lithium-drifted silicon spectrometer. Efforts are being made to improve reproducibility in monitor calibrations and delivered doses. An additional monitor has been added to the electron Van de Graaff beam line, as well as a beam collimator to better specify the beam direction. During FY86 these beams will be used to make further measurements of electron response functions of beta-sensitive radiation protection instruments.

Extension of Instrument Calibration Capability to 6.5-MeV Photons (C. G. Soares)

An approximately 6.5-MeV photon beam is obtained from the $^{19}F(p,\alpha\gamma)^{16}O$ reaction using protons produced in the positive-ion Van de Graaff generator using a thick CaF_2 target. Pulse-height distributions were measured with an intrinsic Ge detector and a NaI(Tl) detector whose response functions are known. Progress was slow during FY85 due to difficulties with the accelerator and the spectral unfolding procedures. The energy of the incident proton beam was increased from 2 to 2.7 MeV in order to increase the high-energy photon output of the reaction, and pulse-height spectra were remeasured at this higher proton energy. When the accelerator is again available, the in-phantom parallel-plate ionization chamber will be used to attempt more accurate dosimetry than was possible at the lower photon output with thermoluminescent dosimeters. It is expected that the salient features of the results will be incorporated in an international standard being developed under the auspices of ISO/TC 85/SC 2/WG 2.

Beta-particle Source Calibration and Associated Measurement Assurance Services (J. S. Pruitt)

The NBS extrapolation chamber has been used with the standard beta-particle sources (^{147}Pm, ^{204}Tl, and $^{90}Sr+^{90}Y$) for a variety of measurements during FY85. These include: comparison of depth-dose curves for three $^{90}Sr+^{90}Y$ sources with different encapsulations; calibration of three other $^{90}Sr+^{90}Y$ sources as a function of source distance; comparison of the noise characteristics of two low-noise cables; measurement of the correction factor for attenuation in the chamber volume; confirmation of the correction factor for ion recombination and diffusion; and calibration of beam monitors in two accelerators that generate approximately monoenergetic electron beams with energies between 0.1 MeV and 2.5 MeV. The last-mentioned study produced some unwanted background current in the extrapolation chamber, so another chamber was purchased, and one is now reserved for low-intensity measurements, and the other for high-intensity measurements.

An accurate digital voltmeter and a calibrated capacitor were transported to the Idaho National Engineering Laboratory to calibrate the electrometer used there for beta-particle measurements. The electrometer was then used to calibrate their ^{204}Tl and ^{147}Pm sources, thus effectively providing an NBS calibration without transporting their sources. These calibrations provided a good check on previous measurements of the effect of decreased atmospheric pressure on beta-particle source calibrations.

The plane-parallel ionization chamber previously obtained and calibrated for use as a transfer instrument was sent to Argonne National Laboratory, Idaho Falls Laboratory (DoE), and Battelle Pacific Northwest Laboratory. At each of the institutions the chamber was calibrated with beta-particle sources that are essentially the same as the NBS sources, and the NBS calibrations were repeated after the chamber was returned. Some of the results are very close, and some less close, but due to variations in the measurement conditions, the interpretation of the results is still under consideration at the time of writing.

Absorbed Dose Calorimetry (S. R. Domen)

The graphite-water calorimeter has been brought into operation. Absorbed-dose measurements are made in a small mass of graphite immersed in water. Adding graphite slabs will allow extrapolation to zero graphite thickness, giving water absorbed dose while circumventing the problem of the water heat defect. The same graphite slabs, without the water, will convert this instrument to an all-graphite calorimeter, thus allowing comparison with previous NBS measurements. Comparison of the graphite-water calorimeter, the polystrene-water calorimeter, and the graphite calorimeters will provide a reliable NBS absorbed dose standard. Preliminary measurements are in agreement with earlier results, indicating an exothermic effect of about 3 to 4 percent in water that is not ultra-clean.

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SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 536, Ionizing Radiation

International Conference on "Mechanisms of DNA Damage and Repair. Implications for Carcinogenesis and Risk Assessment". Chairman: M. G. Simic, Co-chairmen: L. Grossman, A. D. Upton. NBS, June 2-7, 1985.

J. M. Calhoun served as Conductor of the Engineering and Chemistry Forum of the Woman-Owned Small Business Symposium organized by the Department of Commerce in May 1985.

J. M. R. Hutchinson, ICRM Conference on Low-Level Measurement Techniques, Grenoble, France, June 3, 1985.

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INVITED TALKS

Division 536, Ionizing Radiation

Behrens, J. W., "Applied Neutron Physics at the NBS," GWI, Uppsala, Sweden, October 1984.

Behrens, J. W., "Recent Research in Experimental Neutron Physics," Harwell, England, November 1984.

Behrens, J. W., "Fission Cross Section Systematics in the MeV Range," at ENEA, Comitato Nazionale Per l'Energia Nucleare, Bologna, Italy, December 1984.

Behrens, J. W., "Applied Neutron Physics at the NBS," FOA, Stockholm, Sweden, December 1984.

Berger, M. J., "Electron Stopping Powers and Ranges," IAEA Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and Radiobiology, Radiobiological Institute TNO, Rijswijk, The Netherlands, September 16-20, 1985.

Calhoun, J. M., "Radioactivity Measurements at NBS", Womens Forum, Standards Committee for Women, NBS, Gaithersburg, MD, March 20, 1985.

Carlson, A. D., "The Neutron Cross Section Standards Evaluations for ENDF/B-VI," The International Atomic Energy Agency (IAEA) Advisory Group Meeting on Nuclear Standard Reference Data, Geel, Belgium, November 12, 1984.

Carlson, A. D., "The ENDF/B-VI Evaluations of the Neutron Cross Section Standards," Conf. on Nuclear Data for Basic and Applied Science, Santa Fe, NM, May 17, 1985.

Carlson, A. D., "Nuclear Data Standards," American Nuclear Society, Boston, MA, June 13, 1985.

Caswell, R. S., "Nuclear Data for Biomedical Applications", Conference on Nuclear Data for Basic and Applied Science, Santa Fe, NM, May 13-17, 1985.

Collé, R., "Experts' Panel on Error Analysis", National Conference of Standards Laboratories, 1984 Workshop and Symposium, NBS, October 1-4, 1984.

Coursey, B. M., "A $4\pi\beta$(LS) Computational Method for Standardizing Beta-Emitting Nuclides in Secondary Laboratories", ICRM Working Group on Techniques for Radionuclide Metrology, Grenoble, France, June 4, 1985.

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Division 536, Invited Talks (cont'd.)

Coyne, J. J., "Neutron Dosimetry with TE Ionization Chambers and Proportional Counters," Rudjer Boskovic Institute, Zagreb, Yugoslavia, April 9, 1985.

Coyne, J. J., "Neutron Kerma Factors and Their Importance for Neutron Dosimetry," Bulgarian Academy of Science, Institute for Nuclear Science and Energy, Sofia, Bulgaria, April 12, 1985.

Dizdaroglu, M., "Mechanisms of Biological Crosslinks in Model Systems", National Research Council of Canada, Ottawa, Canada, September 1985.

Dizdaroglu, M., "Characterization of Free Radical-Induced Base Damage in DNA", National Research Council of Canada, Ottawa, Canada, September 1985.

Dizdaroglu, M., "The Use of GC-MS for Characterization of Radiation-Induced DNA Base Damage", Armed Forces Radiobiology Research Institute, Bethesda, MD, April 1985.

Duvall, K. C., "The Development of a 6 to 7 MeV Photon Field for Instrument Calibration," Application of Accelerators in Research and Industry, Denton, TX, November 12-14, 1984.

Ehrlich, M., "NBS Facilities for the Study of Radiation Protection Instruments", Personnel Radiation Dosimetry Symposium, Knoxville, Tennessee, October 1984.

Eisenhower, E. H., "Radiation Measurement Support System", Region X Radiation Control Program Meeting, Seattle, WA, February 19, 1985.

Eisenhower, E. H., "The National Support System for Measurement Quality Assurance", Topical Symposium on Quality Assurance in Ionizing Radiation Measurement, Health Physics Society, Kennewick, WA, March 14, 1985.

Gilliam, D. M., "Cross Section Measurements in the ^{235}U Fission Spectrum Neutron Field", Fifth ASTM-EURATOM Symposium on Reactor Dosimetry, Geesthacht, West Germany, October 1984.

Hoppes, D. D., "Radioactivity Measurement Programs at NBS", Institute d'Electrochimie et Radiochimie, Lausanne, Switzerland, June 1, 1985.

Hoppes, D. D., "Basic Radionuclide Measurements", ICRM Working Group on Techniques for Radionuclide Metrology, Grenoble, France, June 4, 1985.

Hoppes, D. D., "Photon Spectrometry from 5 to 100 keV", ICRM Gamma-Ray-Spectrometry Working Group, Grenoble, France, June 5, 1985.

Division 536, Invited Talks (cont'd.)

Hubbell, J. H., "Photon Interaction Data for Radiation Dosimetry. Current Status and Prospects," Laboratorio di Metrologia dell Radiazioni Ionizanti, ENEA, Istituto Casaccia, Rome, Italy, October 23, 1984.

Hubbell, J. H., "Acceptance of 1985 Society of Nuclear Medicine Paul C. Aebersold Award," 32nd Annual Meeting of the Society of Nuclear Medicine, Houston, Texas, June 2, 1985.

Hutchinson, J. M. R., "Low-level Progress Report - NBS", ICRM Working Group on Low-Level Measurement Techniques, Grenoble, France, June 3, 1985.

Hutchinson, J. M. R., "Sputter-Induced Resonance Ionization Spectrometry", ICRM Working Group on Techniques for Radionuclide Metrology, Grenoble, France, June 4, 1985.

Inn, K. G. W., "Reference Materials for Atom-Counting Cosmo-Geochemistry Measurements?", The 1984 International Chemical Congress of Pacific Basin Societies, Honolulu, Hawaii, December 16-21, 1984.

Inn, K. G. W., "Chemical Challenges in the Certification of Environmental-level Radioactivity Standard Reference Materials", University of Arkansas, Fayetteville, Arkansas, July 3, 1985.

McLaughlin, W. L., "Fiber Optics Dosimetry", Accelerator and Chemistry Department, Riso/National Laboratory, Roskilde, Denmark, October 4, 1984.

McLaughlin, W. L., "The Measurement of High Doses Near Metal and Ceramic Interfaces", International Symposium on High Dose Dosimetry, International Atomic Energy Agency, Vienna, Austria, October 9, 1984.

McLaughlin, W. L., "Response of Radiochromic Film Dosimeter to Gamma Rays in Different Atmospheres", International Symposium on High Dose Dosimetry, International Atomic Energy Agency, Vienna, Austria, October 11, 1984.

McLaughlin, W. L., "Energy Dependence of Radiochromic Response to X and Gamma Rays", International Symposium on High Dose Dosimetry, International Atomic Energy Agency, Vienna, Austria, October 12, 1984.

McLaughlin, W. L., "Standardization of High Dose Measurement of Electron and Gamma-Ray Absorbed Dose and Dose Rates", International Symposium on High-Dose Dosimetry, International Atomic Energy Agency, Vienna, Austria, October 12, 1984.

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Division 536, Invited Talks (cont'd.)

McLaughlin, W. L., "Food Irradiation Dosimetry by Optichromic Techniques", 5th International Meeting on Radiation Processing, San Diego, CA., October 24, 1984.

McLaughlin, W. L., "Response of Radiochromic Film Dosimetry to Gamma Rays in Different Atmospheres", 5th International Meeting on Radiation Processing, San Diego, CA., October 25, 1984.

McLaughlin, W. L., "Plastic Film Materials for Dosimetry of Very Large Absorbed Doses", 5th International Meeting on Radiation Processing, San Diego, CA., October 25, 1984.

McLaughlin, W. L., "Response of Radiation Monitoring Labels to Gamma Rays and Electrons", 5th International Meeting on Radiation Processing, San Diego, CA., October 25, 1984.

McLaughlin, W. L., "Dosimetry for Applied Radiation Technologies", Radiological Sciences Dept., Battelle NW, Richland, WA., November 1, 1984.

McLaughlin, W. L., "Calorimeters as Electron-Beam High-Dose Primary Standards", Accelerator Department Seminar, Riso/National Laboratory, Roskilde, Denmark, May 22, 1985.

McLaughlin, W. L., "Radiation Dosimetry with Radiochromic Dyes", NBS-Boris Kidric Institute Seminar, Boris Kidric Inst. of Nuclear Science, Vinca, Belgrade, Yugoslavia, June 11, 1985.

McLaughlin, W. L., "Validation Procedures and Dosimetry in Routine Industrial Radiation Sterilization", U.S. Food and Drug Administration Training Course, Ramada Inn, Culver City, CA., June 26, 1985.

McLaughlin, W. L. and Humphreys, J. C., "Industrial Radiation Technology", FMC Corporation, Santa Clara, CA, September 26, 1985.

Radak, B. and McLaughlin, W. L., "Radiation Dosimetry with Radiochromic Dyes", Seminar on Scientific Cooperation between NBS and IBK in the 1980-1985 period, Boris Kidric Inst. of Nuclear Science, Belgrade, Yugoslavia, June 10-11, 1985.

Seltzer, S. M., "Calculated Depth-Dose Distributions in Multi-layer Media Irradiated by Electrons," Conference on Applications of Accelerators in Research and Industry, Denton, Texas, November 12-14, 1985.

Schwartz, R. B., "Neutron Personnel Dosimetry Calibration", Personnel Radiation Dosimetry Symposium, Knoxville, Tennessee, October 17, 1984.

Simic, M. C., "Fat Oxidation and Antioxidants", Nabisco Brands Lipid Symposium, Nabisco, Rochelle Park, N.J., November 15-16, 1984.

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Division 536, Invited Talks (cont'd.)

Simic, M. G., "What's New in DNA Damage", Association for Radiation Research", U. Newcastle, England, December 18-21, 1984.

Simic, M. G., "Dosimetry of Dosage Received. Irradiated Foods: A New Business", Food Processors Institute, San Francisco, CA, February 15, 1985.

Simic, M. G., "Antioxidants. Kinetics and Mechanisms", Lipid Oxidation Symposium, Am. Chem. Soc., Miami Beach, FL., April 28 - May 3, 1985.

Simic, M. G. and Dizdaroglu, M., "Mechanisms of Free Radical Crosslinking in Biological Model Systems", Radiation Research Soc., Los Angeles, CA., May 3-9, 1985.

Simic, M. G., "Free Radical Mechanisms of DNA Base Damage", First Conference on Mechanisms of DNA Damage and Repair, NBS, Gaithersburg, MD, June 2-7, 1985.

Simic, M. G., Dizdaroglu, M., and Karam, L., "Chemical Analysis of Irradiated Foods", Am. Nuclear Soc., Boston, MA., June 10-15, 1985.

Simic, M. G. and AlShiekhly, M., "Superoxide Radical Generation in Radiation-induced Autoxidation of Fatty Acids", 4th Int. Conf. on Superoxide and Superoxide Dismutase, Rome, Italy, September 1-6, 1985.

Soares, C. G., "Development of Monoenergetic Electron Beam Sources for Radiation Instrument Calibration", 8th Conference on Application of Accelerators in Research and Industry, Denton, Texas, November 13, 1984.

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Lett, J. T. Cox, A. B., and Bergtold, D. S., Cellular and Tissue Responses to Heavy Ions: Basic Considerations, Radiation and Environmental Biophysics (1985) (in press).

Lett, J. T., Bergtold, D. S., and Keng, P. C., DNA damage and its repair in rabbit sensory cells, In: Mechanisms of DNA Damage and Repair: Implications for Carcinogenesis and Risk Assessment, M. G. Simic, L. Grossman and A. D. Upton, eds., (Academic Press: New York). 1985 (in press).

McDonald, J. C., and Domen, S. R., A-150 Plastic Radiometric Calorimeter for Charged Particles and Other Radiations, Nucl. Instr. Meth. (in preparation).

McLaughlin, W. L., Radak, B. B., Silverman, J., Liu Zhan Jun, Miller, A., Bastberg-Pedersen, W., and Charlesby, A., High Density Polyethlene Film Dosimetry by Infrared Spectrophotometry of Transvinylene Unsaturation, to be submitted to Radiation Physics and Chemistry (1985).

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Division 536, Publications in Preparation (cont'd.)

McLaughlin, W. L., Radak, B. B., and Farahani, M., "Measurement Quality Assurance in the Radiation Treatment of Foods, Trans. Am. Nucl. Soc. (in press).

Neta, P. and Simic, M. G., Free Radical Chemistry of Natural Products, Inst. Food Tech. (in press).

Pruitt, J. S., The Effect of Altitude on Beta-Ray Source Calibrations, Rad. Protect. Dosim. (in press).

Radak, B. B., McLaughlin, W. L., and Simic, M. G., Enhanced Sensitivity of Chemical Dosimeters Using Liquid Core Optical Wave Guides, submitted to Nuclear Instruments and Methods (1985).

Schrack, R. A., A Microchannel Plate Neutron Detector, Chapter in International Advances in Nondestructive Testing (in press).

Schrack, R. A., New Applications of Resonance Neutron Radiography, Radiation Effects (to be published).

Schroder, I. G., Linpei, Li, Gilliam, D. M., McGarry, E. D. and Eisenhauer, C. E., Measurement of Absolute Fission Cross Sections for ^{252}Cf Spontaneous Fission Neutrons, Nuclear Trans. (in press).

Schwartz, R. B., Guidelines for the Establishment and Operation of a Secondary Standard Dosimetry Laboratory for Neutrons, IAEA Technical Reports Series (in press).

Seltzer, S. M. and Berger, M. J., Bremsstrahlung Spectra from Electron Interactions with Screened Atom Nuclei and Orbital Electrons, Nucl. Instr Methods B (in press).

Seltzer, S. M. and Berger, M. J., Bremsstrahlung Energy Spectra from Electrons with Kinetic Energy 1 keV-10 GeV Incident on Screened Nuclei and Orbital Electrons of Neutral Atoms with Z = 1 - 100, Atomic Data & Nucl. Data Tables (in press).

Simic, M. G. and Hunter, E. P. L., Antioxidants, Inst. Food Tech. (in press).

Simic, M. G., Free-radical Mechanisms of DNA Base Damage, International Conference on Mechanisms of DNA Damage and Repair, NBS, Gaithersburg, MD, June 7, 1985, J. Res. NBS (in press).

Trochon, J., Simon, G., Behrens, J. W., Brisard, F., and Signarbieux, C., Cold Fragmentation in Thermal Neutron Fission at ^{235}U, Radiation Effects (to be published).

Division 536, Publications in Preparation (cont'd.)

Wasson, O. A., Progress in the Detection of Low-Energy Neutrons, Proc. 4th International Symposium on Neutron-Induced Reactions, Smolenice, Czechoslovakia, June 17-21, 1985 (in press).

Wasson, O. A., Carlson, A. D., and Duvall, K. C., Analysis of the Effect of Random Events on the 14 MeV U-235(n,f) Cross Section Measurement, Radiation Effects (to be published).

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TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 536, Ionizing Radiation

James W. Behrens

Chairman, Nuclear Data Committee of the Isotopes and Radiation Division, American Nuclear Society.

Member, Transuranic Task Force, of the Isotopes and Radiation Division, American Nuclear Society.

Member, Cross Section Evaluation Working Group, National Nuclear Data Center, Brookhaven National Laboratory.

Martin J. Berger

Member, International Atomic Energy Agency Advisory Group on Nuclear and Atomic Data for Radiotherapy and Radiobiology.

Chairman, International Commission on Radiation Units and Measurements (ICRU), Committee on Stopping Power.

Member, National Council on Radiation Protection and Measurements (NCRP), Committee #52 on Conceptual Basis of Dosimetry.

Member, NCRP, Committee #55 on Experimental Verification of Internal Dosimetry.

Member, Naval Surface Weapons Center Laboratory Review Team of the Naval Research Advisory Committee Panel on Laboratory Oversight.

Member, Naval Research Advisory Committee, Naval Surface Weapons Center Review Panel.

Jacqueline M. Calhoun

Member, National Measurements Laboratory Minority Advisory Panel.

EEO Counselor, NBS, two-year appointment, January 19, 1984 through January 19, 1986.

Allan D. Carlson

Member, Cross Section Evaluation Working Group (CSEWG).

Member, Evaluation Committee of CSEWG.

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Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Allan D. Carlson (cont'd.)

Chairman, Standards Subcommittee, CSEWG.

Member, Data Status and Requests Subcommittee of CSEWG.

Member, Organizing Committee for the International Atomic Energy Agency Advisory Group Meeting on Nuclear Standard Reference Data held in Geel, Belgium, Nov. 12-16, 1984.

Randall S. Caswell

Chairman, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC), Office of Science and Technology Policy.

Alternate Member, CIRRPC, Office of Science and Technology Policy.

Delegate, Consultative Committee for Ionizing Radiations (CCEMRI), Conférence Générale des Poids et Mesures, Paris, France.

Chairman, Section on Neutron Measurements (Section III), CCEMRI, Conférence Générale des Poids et Mesures, Paris, France.

Member, National Council on Radiation Protection and Measurements (NCRP).

Chairman, NCRP Ad Hoc Committee on SI Units.

Chairman, NCRP Ad Hoc Committee on Publications.

Member and Secretary, International Commission on Radiation Units and Measurements (ICRU).

Sponsor, ICRU Report Committee on Stopping Power.

Sponsor, ICRU Report Committee on Absolute and Relative Dosimetry at High Doses.

Sponsor, ICRU Report Committee on Tissue-Equivalent Materials.

Member, Radiation Research Accelerator Facility (RARAF) Scientific Advisory Committee, Columbia University.

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Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Ronald Collé

Member, Science Subpanel on Radon Protection and Health Effects, Committee on Interagency Radiation Research and Policy Coordination.

Member, Radon Working Group, Interagency Committee on Indoor Air Quality.

Delegate, Bureau International des Poids et Mesures (BIPM) Working Group on the Statement of Uncertainties.

Resource Person, Conference of Radiation Control Program Directors, Subcommittee on Radon Measurements.

Resource Person, Conference of Radiation Control Program Directors, Task Force on Criteria for an Adequate Radiation Control Program - Environmental Monitoring and Surveillance.

Bert M. Coursey

Member, International Committee for Radionuclide Metrology (ICRM) Life Sciences Working Group

Member, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of Detectors for Radioactive Materials.

J. Joseph Coyne

Member, CIRRPC Subcommittee on High LET Radiation.

Member, European Community Dosimetry Group (EURADOS) Committee 1: Tissue-Equivalent Proportional Counters as an Instrument for Radiation Protection.

Member, EURADOS Committee 4: Computational Methods and Benchmark Calculations in Radiation Protection.

Member, International Atomic Energy Agency Advisory Group on Nuclear and Atomic Data for Radiotherapy and Radiobiology.

Charles E. Dick

Member, Technical Program Committee, Biannual Conferences on Applications of Small Accelerators in Industry and Medicine.

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Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Margarete Ehrlich

Member, ISO/TC 85/SC 2/WG 2, Photographic Dosimeters and Reference Radiation.

Member, Health Physics Society Standards Committee N13.28, Work Group on Criteria for Testing Environmental Dosimetry Performance.

Member, Work Group on Revision of ANSI/ANS 6.1.1, Neutron and Gamma-Ray Flux-to-Dose Rate Factors, American Nuclear Society.

Member, National Research Council, Commission on Life Sources, Committee on Dose Assignment and Reconstruction for Service Personnel at Nuclear Weapons Test.

Charles M. Eisenhauer

Alternate Member, CIRRPC Science Panel.

Member, National Council on Radiation Protection and Measurements (NCRP) Task Group on Atomic Bomb Survivor Dosimetry: SC-40 Biological Aspects of Radiation Protection Criteria.

Member, ASTM Subcommittee E10.05 on Nuclear Radiation Metrology.

Member, NAS-NRC Advisory Committee on the Radiation Effects Research Foundation Subcommittee: Panel on the Reassessment of A-Bomb Dosimetry.

Member, ANS Standards Committee Working Group on Gamma-Ray Attenuation Data.

Elmer H. Eisenhower

Alternate Representative, ANSI N44, Equipment and Materials for Medical Radiation Applications.

Chairman, ANSI N43, Equipment for Non-Medical Radiation Applications.

Chairman, Interagency Committee on Occupational Radiation Protection Measurements.

Resource Person, Conference of Radiation Control Program Directors, Committee on Radiation Measurements.

Department of Commerce Representative, Interagency Working Group on Occupational Exposure Guidance.

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Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Elmer H. Eisenhauer (cont'd.)

Member, ASTM Subcommittee E10.04 on Radiation Protection Methodology.

Member, Science Subpanel on Scientific Basis for Radiation Protection Standards, Committee on Interagency Radiation Research and Policy Coordination.

Member, Committee on Secondary Calibration Laboratories for Survey Instruments, Health Physics Society.

Leon J. Goodman

Member, Report Committee on Clinical Dosimetry for Neutrons, International Commission on Radiation Units and Measurements.

Consultant, American Association of Physicists in Medicine, Task Group No. 18, Fast Neutron Beam Dosimetry Physics, Radiation Therapy Committee for AAPM Report No. 7, Protocol for Neutron Beam Dosimetry.

James A. Grundl

Member, Steering Committee for Developing ASTM Standards for Reactor Dosimetry, NBS, March 1985.

Member, ASTM Subcomittee E10.05 on Nuclear Radiation Metrology.

H. Thompson Heaton, II

Member, ANSI N43-3.4, Subcommittee for Gamma Irradiators.

Member, ANSI N43-8, Subcommittee for Electron Microscopes.

Resource Person, Conference of Radiation Control Program Directors, Committee on Radiation Measurements.

Dale D. Hoppes

Member, International Committee for Radionuclide Metrology (ICRM) Alpha-, Beta, and Gamma-Ray Spectrometry Working Group.

Member, Atomic Industrial Forum (AIF)-NBS Standards Program Committee.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Dale D. Hoppes (cont'd.)

Member, International Committee of Weights and Measures (BIPM), Consultative Committee on Standards for Measuring Ionizing Radiations, Subcommittee Section II: Radionuclide Measurements.

Member, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of Detectors for Radioactive Materials.

John H. Hubbell

Secretary, Commission on Crystallographic Apparatus, International Union of Crystallography, Task Group on X-Ray Absorption Coefficients.

Chairman, American Nuclear Society (ANS) Radiation Protection and Shielding Division ANS-6 Ad Hoc Committee on SI Units.

Member, Cross Section Evaluation Working Group (CSEWG) Subcommittee on Shielding.

Secretary, Pro-tem Committee, now-forming International Radiation Physics Society.

Acting Chairman, ANS Isotopes and Radiation Division Nuclear Data Committee.

Chairman, General Health Physics Section of the Health Physics Society Standards Committee.

Secretary, International Program Committee for the 3rd International Symposium on Radiation Physics, Ferrara, Italy, Sept. 30-Oct. 4, 1985.

Jimmy C. Humphreys

Secretary, ASTM Committee E10.07, Ionizing Radiation Dosimetry and Radiation Effects on Materials and Electronic Devices.

Member, ASTM-F-1.11, Subcommittee on Quality and Hardness Assurance of the F-1 Electronic Committee.

Member, Association for Advancement of Medical Instrumentation (AAMI), Committee on Radiation Dosimetry.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

J. M. Robin Hutchinson

Chairman, International Committee for Radionuclide Metrology (ICRM) Subcommittee on Low-Level Techniques.

Member, American National Standards Institute (ANSI) Committee on Nuclear Instruments and Detectors.

Secretary, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of Detectors for Radioactivity Measurements.

Kenneth G. W. Inn

Member, American Society for Testing and Materials (ASTM) Committee C26.05 Environmental Methods Task Group on Nuclear Fuel Cycle.

Member, Methods of Radiochemical Analysis in Water and Water Deposits, ASTM Committee D19.04.

George P. Lamaze

Secretary, American Society for Testing and Materials (ASTM), Subcommittee E10.05, Nuclear Radiation Metrology.

Member, ASTM Committee E10, Nuclear Technology and Applications.

Robert Loevinger

Member, BIPM Consultative Committee for Standards for Measurement of Ionizing Radiation, Section I, X- and Gamma-Rays and Electrons.

Member, Medical Internal Radiation Dose Committee, Society of Nuclear Medicine.

Consultant, American Association of Physicists in Medicine (AAPM) Radiation Therapy Committee.

Member, AAPM Radiation Therapy Committee Task Group 3, Regional Calibration Laboratories.

Member, AAPM Radiation Therapy Committee Task Group 21, High-Energy Photon and Electron Dosimetry. (Disbanded August 1985)

Member, AAPM Radiation Therapy Committee Task Group 32, Brachytherapy.

Consultant, AAPM Radiation Therapy Committee Task Group 30, Total Skin Electron Therapy.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Wilfrid B. Mann

Consultant, International Commission on Radiation Units and Measurements (ICRU).

Member, ANSI-INMM Work Group INMM 8.04 on Calibration Techniques for the Calorimetric Assay of Plutonium-Bearing Solids applied to Nuclear Materials Control.

Member, ANSI Subcommittee on Procedural Standards for Calibration of Detectors for Radioactivity Measurements.

Honorary Council Member, National Council on Radiation Protection and Measurements (NCRP).

Chairman, NCRP Committee 18A on Standards and Measurement of Radioactivity for Radiological Use.

Life Member, International Committee for Radionuclide Metrology.

Emmert D. McGarry

Member, Organizing Committee for the Fifth ASTM-Euratom Symposium Reactor Dosimetry, Geesthacht, Germany, September 1984.

Member, ASTM E10.05 Subcommittee on Nuclear Radiation Metrology.

William L. McLaughlin

Chairman, International Commission on Radiation Units and Measurements (ICRU), Committee on Absolute and Relative Dosimetry at High Doses.

Technical Advisor, ICRU Committee on Chemical Dosimetry.

Member, American Nuclear Society (ANS), Subcommittee for Nuclear Terminology and Units, ANS-9.

Chairman, ANS-9.1 Subcommittee, Health Physics and Dosimetry.

Member, ASTM E10.07, Ionizing Radiation Dosimetry and Radiation Effects on Materials and Electronic Devices.

Technical Advisor, Association for the Advancement of Medical Instrumentation, Subcommittee on Radiation Sterilization of Medical Devices, Task on Radiation Dosimetry.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

William L. McLaughlin (cont'd.)

Member, ANS 9.2, Subcommittee on Shielding of the Nuclear Terminology.

Technical Advisor, ISO WG-1, Nuclear Energy Terminology, Task on the ISO TC/85, Committee on Nuclear Energy.

Technical Advisor, Council of Europe Parliamentary Assembly, Work Group on Aerospace Physiology, Medicine, and Radiation Measurement.

Technical Advisor, Council of Europe Parliamentary Assembly, Work Group on Space Biophysics.

Member, R & D Associates Committee on Irradiated Food Products.

Member, International Atomic Energy Agency, Advisory Group on High Dose Measurement and Standardization for Radiation Processing.

Member, Association for Advancement of Medical Instrumentation, Working Group on Radiation Sterilization Dosimetry.

Technical Advisor, National Council on Radiation Protection and Measurement, Scientific Committee 63, Radiation Exposure Control in a Nuclear Emergency.

Science and Technology Consultant, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC).

Member, Advisory Panel on Electron Beam Dosimetry for Industrial Radiation Processing, International Atomic Energy Agency.

Member, Program Committee, 5th International Symposium on Radiation Processing held in San Diego, CA, October 1984.

Member, Organizing Committee, International Workshop on Identification and Dosimetry of Irradiated Food, Federal Republic of Germany's Office of Radiation and Environmental Health and Federal Health Office.

Member, Industrial Panel on Status of Electron and Gamma-Ray Dosimetry for Radiation Processing.

Robert B. Schwartz

Member, International Standards Organization (ISO) Technical Committee 85 (Nuclear Energy), Subcommittee 2 (Radiation Protection), Working Group 2 (Reference Radiations).

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Stephen M. Seltzer

Member, International Commission on Radiation Units and Measurements (ICRU), Committee on Stopping Power.

Oren A. Wasson

Member, U.S. Department of Energy Nuclear Data Committee

Member, General Program Advisory Committee for the International Conference on Nuclear Data for Basic and Applied Science, May 13-17, 1985, Santa Fe, NM.

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MAJOR CONSULTING AND ADVISORY SERVICES

Division 536, Ionizing Radiation

1. J. W. Behrens advised R. J. Howerton (CP-Division) Lawrence Livermore National Laboratory on nuclear data measurement, systematics and evaluation on a continuing basis starting October 1984.

2. A. D. Carlson provided consultation to the U.S. Bureau of Mines on the use of neutron detectors for determining the neutron output of a neutron producing accelerator.

3. A. D. Carlson consulted with the International Atomic Energy Agency on the development of the Monitor Reactions portion of the Nuclear Activation Data Handbook.

4. A. D. Carlson advised North Carolina State University on nuclear data for use in well logging experiments.

5. R. Collé advised the indoor air quality research group at the Harvard School of Public Health on the design and preparation of a radium source for continuous radon generation.

6. R. Collé advised and assisted staff members in various NBS divisions on the treatment and reporting of measurement uncertainties.

7. R. Collé visited radiation control program personnel in the Wisconsin Department of Health and assisted on calibration procedures and facilities for radon measurements.

8. C. E. Dick, Dr. F. J. Sazama, Harry Diamond Lab., Silver Spring, MD., vacuum fittings for accelerator systems.

9. C. E. Dick, Dr. Michael Moran, Lawerence Livermore Nat'l. Lab., Livermore, CA, beam coherence in transition radiation.

10. C. E. Dick, Dr. H. Hendlowitz, Dr. Sol Glass, Howard Univ. Physics, Wash., DC, coherence effects for Cerenkov radiation.

11. C. E. Dick, Clinton Richmond, Naval Surface Weapons Center, Silver Spring, MD, coherence effects in Cerenkov radiation at low energies (possible collaboration on 500 kV set).

12. C. E. Dick, Dr. Larry Fagg, Dept. of Phys., Catholic Univ. of America, Washington, DC, calibration of electron spectrometer (magnetic deflection and Ge(Li) detector).

Division 536, Major Consulting and Advisory Services (cont'd.)

13. C. E. Dick, Dr. Steven Segall, KMS Fusion, Ann Arbor, MI, use of Van de Graaff accelerator for nanosecond electron beam compression.

14. C. E. Dick, Dominique Gignoux & Michael Mullendore, Data Meas. Corp., Gaithersburg, MD, x-ray thickness gauging of composite materials.

15. C. E. Dick, Jean-Charles Hardouin, Guerbet Corp., Paris, France, measurement of the physical properties of halogenated compounds used as radiographic contrast media.

16. C. E. Dick, M. Moran and T. Shaeffer, Lawrence Livermore Nat'l. Lab., Livermore, CA, coherent QED effects at MeV energies, i.e. Smith-Purcell, Transition Radiation, etc.

17. C. E. Dick, Mr. Clinton Richmond, NSWL as above, measurements on 500 kV set at approximately weekly intervals. Coherence effects in Cerenkov radiation.

18. C. E. Dick, Mr. Michael Reidinger, Tru-Lyte Systems, Inc., East Girard, PA, accelerator usage for particle releasement for SDI.

19. S. R. Domen provided advice to the Calgary Cancer Clinic, Calgary, Alberta, on the construction and operation of an absorbed dose water calorimeter.

20. S. R. Domen provided advice on construction of absorbed dose water and polystyrene-water calorimeters, to the Massachusetts General Hospital.

21. S. R. Domen provided consultation and advice on absorbed dose standards to Dr. A. Jakob of the National Office of Measures, Budapest, at NBS during September 1985.

22. K. C. Duvall provided consultation to Consolidated Controls Corporation, Springfield, Va. on the use of solid state detectors for associated particle measurements within portable, sealed-tube D-T generators.

23. M. Ehrlich consulted with a committee of the Health Physics Society concerning the feasibility of establishing accredited secondary calibration laboratories for radiation protection purposes.

24. M. Ehrlich carried out site inspections of calibration facilities at the Idaho National Engineering Laboratory, Idaho Falls, and at Battelle Pacific Northwest Laboratories, Hanford, for the Department of Energy Laboratory Accreditation Program (DOELAP), in November 1984.

Division 536, Major Consulting and Advisory Services (cont'd.)

25. M. Ehrlich provided guidance for the National Academy of Sciences for irradiation at NBS of thermoluminescent samples from Hiroshoma and Nagasaki.

26. M. Ehrlich provided expert advice to the Johns Hopkins University Radiation Dosimetry Advisory Committee, which is concerned with personnel dosimetry for Navy shipyard workers some 25 years ago.

27. D. M. Gilliam is advising and assisting Babcock and Wilcox in preparation of high-level dosimeters for measurements in mixed gamma and neutron radiation fields at commercial nuclear reactors. These measurements are being made for assessing the integrity of reactor pressure vessels and understanding radiation shielding for reducing personnel exposure.

28. H. T. Heaton, II advised the Illinois Department of Nuclear Safety on calibration sources and procedures for environmental thermoluminescence dosimetry.

29. J. C. Humphreys provided comprehensive experimental design plan for testing of new polymer dosimeter for various parameters such as temperature dependence, stability of response, effects of environment and dose rate dependence. (Dr. T. Prusik, Allied Corp. Morristown, NJ).

30. J. C. Humphreys provided two days of on-site discussions and lectures on electron beam calorimetry design and absorbed dose measurements with radiochromic thin films (R. Christinat, Becton Dickinson, Canaan, CT).

31. J. M. R. Hutchinson served as "Expert" to the Institute for Radioprotection, Rio de Janiero, Brazil, to advise on the development of their low-level program.

32. K. G. W. Inn reviewed radiochemical quality control procedures at Los Alamos National Laboratory, Los Alamos, New Mexico.

33. R. Loevinger consulted with a committee of the Health Physics Society concerning the feasibility of establishing accredited secondary calibration laboratories for radiation protection purposes.

34. R. Loevinger provided consultation to the Dosimetry Section of the International Atomic Energy Agency concerning organization and operation of the IAEA/WHO network of Secondary Standard Dosimetry Laboratories.

Division 536, Major Consulting and Advisory Services (cont'd.)

35. W. L. McLaughlin, Medical Sterilization, Inc., Dr. Michael Fogarty and Dr. K. H. Morganstern. Supplied consulting services on electron beam dose measurements in the sterilization and substerilization range and design radiation methods for sterilization by 1 to 5 MeV electron beams; determine effects of humidity, temperature, and dose rate on radiochromic film response to electrons.

36. W. L. McLaughlin, Drs. Grillo and V. Deffner (Directors of Gesellschaft fur Strahlen-und Umsweltforschung, Munich). Advised them on national and international dosimetry standardization at high doses with gamma radiation.

37. W. L. McLaughlin, Department of Energy, Dr. D. Ballentine. Provided methodology for evaluating (materials testing) of polymers as a means of end-point analysis for high-dose dosimetry.

38. W. L. McLaughlin, Naval Surface Weapons Lab., Dr. M. Brown, Dr. S. Stern. Served on panel for designing area dose monitoring in intense charged particle beams.

39. W. L. McLaughlin, Allied Corporation, Dr. T. Prusik. Provided thorough background material and a number of systems and analytical tools for radiochromic dosimetry for use in food irradiation.

40. W. L. McLaughlin, Stanford Research Inst., Dr. G. Taimuty. Consulted on new high-dose dosimetry systems for study by SRI.

41. W. L. McLaughlin, Wolf X-ray Corp., Dr. Martin Wolf. Evaluated TLD, film badge, and solid-state detector responses as a function of x-ray photon energy.

42. W. L. McLaughlin, University of Lowell, Rad. Lab., Dr. Fred McWilliams. Designed high-dose measurement system for standardizing large ^{60}Co source dose levels (traceability to standards).

43. W. L. McLaughlin, Syntex Corp., Dr. Carol Lemelson. Devised proper correction factors for erroneous dosimetry readings in radiation sterilization applications.

44. W. L. McLaughlin, Energy Sciences, Inc., Dr. S. V. Nablo, Dr. Ken Williams. Visit from Dr. Williams on low-energy electron beam dosimetry and interface dosimetry.

45. W. L. McLaughlin, Isomedix, Inc., Dr. Michael Saylor. Provided detailed instruction on the use of the new optichromic dosimeter and radiochromic film dosimeters.

Division 536, Major Consulting and Advisory Services (cont'd.)

46. W. L. McLaughlin, Nepera Co., Inc., Dr. Preston Keusch. Gave details of methods of electron beam dosimetry at very high dose rates for industrial applications (plastic crosslinking and insulation improvement).

47. W. L. McLaughlin, Riso National Lab., Chem. Dept., Dr. B. Skytte Jensen. Designed chemical synthesis of pure lecuo forms of radiochromic dyes.

48. W. L. McLaughlin, visit from Drs. Dennis Strickland and Donald Rheme, HHS-NIH, advised on dosimetry and MAP for food irradiation.

49. W. L. McLaughlin, Radiation Science Dept., National Phys. Lab., Dr. John Barrett. Provided detailed description of optimum calibration methods for liquid-ampoule aqueous chemical dosimeters for intercomparison studies.

50. W. L. McLaughlin, Radiation Sterilizers, Inc., Dr. Thomas Hurley. Designed experiments for comparison of different types of high dose dosimeters for use in quality control in radiation sterilization.

51. W. L. McLaughlin, Battelle NW Pacific Labs, Dr. Joseph McDonald. Designed procedures for setting up secondary standards high-dose calibration lab.

52. W. L. McLaughlin, Firestone, Inc., Dr. George Bohm and Dr. J Tucebrem. Suggestions of radiation effects analysis for end-point dosimetry in the irradiation of elastomers.

53. W. L. McLaughlin, International Nutronics, Inc., Mr. Tom Rensel. Detailed correction factors for calculating absorbed dose in different absorbers (Bragg-Gray corrections).

54. W. L. McLaughlin, J. P. Laboratories, Inc., Dr. Gordon Patel. Assisted in development of color dose indicators for radiation sterilization and food processing.

55. W. L. McLaughlin, Buckeye Cellulose Corp., Dr. Ralph Sellers. Dosimetry quality assurance methods for radiation sterilization and sterility validation protocols.

56. W. L. McLaughlin, Neutron Products, Inc., Dr. Dudley Woodard. Gave advice on radiation chemistry of radiochromic dyes and dyed plastics.

57. W. L. McLaughlin, Argonne Nat. Lab., Dr. Warren McGonnagle. Detailed discussion of pulsed beam dosimetry using liquid dye dosimeter solutions.

Division 536, Major Consulting and Advisory Services (cont'd.)

58. W. L. McLaughlin, General Food, Inc. Special irradiation (γ-rays) of food processing dosimeters.

59. W. L. McLaughlin, Lawrence Berkley Lab., Dr. C. A. Tobias and Dr. D. Denney. Design of special thin film dosimeters for heavy-particle dosimetry. Radiation response of triphenylmethane dyes.

60. W. L. McLaughlin, Becton Dickinson, Mr. Robert Christenant. Detailed discussion of thin film dosimetry and calibration, dose rate dependence, temperature dependence, γ-rays versus electron beams.

61. W. L. McLaughlin, Bitek Corp, Mr. Bill Bacick. Detailed discussion of radiochromic film dosimetry and sources of error for electron beam quality control (radiation processing).

62. W. L. McLaughlin, United Technologies, Inc., Essex Group, Dr. Fred Phillips. Instruction on the measurement of high doses and quality control with industrial electron accelerators.

63. W. L. McLaughlin, Isotech, Inc., Dr. Gary Pageam. Described methods of commissioning of both gamma-ray and 10-MeV LINAC radiation processing facilities (protocols).

64. W. L. McLaughlin, Werk Pfaffikon,, Zurich, Switzerland, Dr. Hans Widmer. Development of high-dose hydrophobic dye dosimeters for electron beam applications in industry.

65. W. L. McLaughlin, Becton Dickinson, Dr. Richard Lasslett. Determine response characteristics and accuracy of a new Japanese platics (polymethyl methacrylate) dosimeter (Radix RN-15) for sterilization quality control.

66. W. L. McLaughlin, Insul-Tab, Inc., Dr. Clement Bourgault. Determine response characteristics of a dyed cellulose triacetate film dosimeter for very high doses of low energy electron beams.

67. W. L. McLaughlin, Kleer-View Index, Inc., Dr. John Wos. Determine response characteristics of a dyed polyvinylchloride film dosimeter for moderately high doses of low-energy electron beams, including optimization of post-irradiation heat treatment.

68. W. L. McLaughlin, American Converters, American Hospital, Supply Corp., Dr. H. Schafter, Ruth Garcia. Designed commissioning dosimetry protocol and standard procedures for administrating high-doses of gamma-rays to large volumes of surgical supplies.

Division 536, Major Consulting and Advisory Services (cont'd.)

69. W. L. McLaughlin, Champlain Cable Corp, Dr. Richard Waldron. Supplied new techniques of film dosimeters to replace blue cellophane as a dosimeter for industrial electron-beam applications.

70. W. L. McLaughlin, Food and Drug Admin., Dr. Leonard Nessen. Provided measurement quality assurance procedures for the radiation sterilization of medical devices.

71. W. L. McLaughlin, Escuela Politecnica Nacional, Equador, Dr. Trajano Kamires. Provided calibrated dosimeters in collaboration with Industrial and Dosimetry Section (Dr. V. M. Markovic) of International Atomic Energy Agency, Vienna, Asutria.

72. W. L. McLaughlin, Atomic Energy of Canada, Ltd., Dr. Michael Antoniades. Measurement assurance methods for gamma-ray industrial applications.

73. W. L. McLaughlin, Department of Commerce, Office of Reg. and Federal Programs Analysis, Dr. Phillip Lewis. 1984-1985 new development in large radiation source technology (gamma rays, x-rays, and electron beams) for industrial applications.

74. W. L. McLaughlin, Southwest Research, Inc., Mr. David Cadena, Jr. Methods of standardizing the high-dose response of solid-state dosimeters (alkali halide crystals) against their thermoluminenescence response characteristics.

75. W. L. McLaughlin, Kimball, Inc., Dr. Nancy Trewin. Methods of standardizing radiochromic film dosimeters for sterilization by ionizing radiation.

76. W. L. McLaughlin, Conservatome, France, Dr. B. Dove. Advised on the available methods of standardizing red Perspex dosimeters for radiation sterilization applications.

77. W. L. McLaughlin, Association for Dressings and Sauces, Dr. Jane McDonald. Conducted tour of CRR and lecture to members of Assocation on dosimetry for food irradiation.

78. W. L. McLaughlin, IRT Corp., Dr. Elaine Bondos. Supplied rate dependence data for radiochromic film dosimeter response to electron beams, for applications in doping semi-conductors and lithography with LINAC radiation sources.

79. W. L. McLaughlin, Harvard Med. School, Dept. of Radiology, Dr. Goran Svensson. Mapping of radiation doses in cancer patients being treated by high energy charged particle beams (protons).

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Division 536, Major Consulting and Advisory Services (cont'd.)

80. W. L. McLaughlin, Univ. of Nebraska, Dept. of Physics, Dr. M. P. R. Waligorski. Developed tissue equivalent dosimeters for high-LET radiations (heavy charged particles and neutrons).

81. W. L. McLaughlin, UK National Rad. Protection Board, Dr. J. C. Dutt. Provide guidelines for standardization of high-dose measurement of electron and gamma-ray dosimetry for industrial applications.

82. W. L. McLaughlin, Abbott Laboratories, Mr. Carlos Parra. Description and protocol for use of dye dosimeters for standardizing radiation sterilization by large ^{60}Co gamma-ray sources.

83. W. L. McLaughlin, IMED Corp., Dr. Edward F. Waddell. Devised improved dosimetry methods for accurate determination of comparative responses of various microbe populations to gamma rays and electron beams in radiation sterilization.

84. W. L. McLaughlin, Assistance Industrelle Dauphinoise, France, Dr. P. Marion. Designed techniques for use of very thin radiochromic films to measure dose distribution interfaces of materials irradiated by electrons.

85. W. L. McLaughlin, CERN, Geneva, Switzerland, Dr. H. Schonbacher. Designed a color film (radiochromic) visual monitor for long-term radiation damage detection in magnets in large ring charged particle beam lines.

86. W. L. McLaughlin, IRT Corp., Dr. Andrew Weiman. Assisted in formulating methods for calibrating thin film dosimeter response in silicon to gamma rays and electron beams at high fluence rates.

87. W. L. McLaughlin, Design Magnetics Corp., Dr. Mark Smith. Design an experiment and test method with thin-film dosimeters for improving accuracy and quality control in the radiation processing of magnetic tape, using 100-300 keV electron beams. Attend meetings on food irradiation policy and technology issues.

88. W. L. McLaughlin, Baxter-Travenol, Dr. Monte Wisler. Provided response data for new Japanese clear plastic. (polymethylmethacrylate) dosimeter (Radix RN-15).

89. W. L. McLaughlin, NASA-Goddard and Hampden-Sydney College. (Prof. Thomas Joiner). High-dose dosimetry procedure design for semiconductor device arrays (very high doses).

Division 536, Major Consulting and Advisory Services (cont'd.)

90. W. L. McLaughlin, Argatom, Dr. Riccardo Bustamante, Dr. Raul Fitte, President. Provided details of gamma-ray irradiator design and dosimetry for industrial applications, radiation testing, and processing.

91. W. L. McLaughlin, Synchron Corp, Dr. John Harris. Develop quality control methods for uniform irradiation and monitoring for the sterilization and large quantities of human blood (quantities in tons).

92. W. L. McLaughlin, Abbott Laboratories, Dr. M. Capp, Carl Bods. Provided descriptions and correction factors of ceric-cerous aqueous chemical dosimetry systems.

93. W. L. McLaughlin, Food Irradiation Research Committee, Dr. J. M. Wagland. Provided detailed food irradiation dosimetry data for quality control in the irradiation of various food types.

94. W. L. McLaughlin, Radiation Technology, Inc., Dr. M. S. Fidan. Supplied patent information and radiation chemical anaylsis methods for stereospecific polymers, including particularly polyethylene, polystyrene, and polypropylene.

95. W. L. McLaughlin, California Dept. of Food and Agriculture, Dr. Joseph Rothleder. Supplied details of fiber optics dosimetry for quality control and standardization of food irradiation.

96. W. L. McLaughlin, Kernonturkkelingskorporasie, South Africa, Dr. Hendrik vander Linde. All day visit to learn about MAP procedures for standardizing high dose dosimetry for industrial applications.

97. W. L. McLaughlin, Chinese Delegation visits. Dr. Xie, Dr. Lin, Director Public Health, Beijing. Radiation measurement standardization for medical and health applications.

98. W. L. McLaughlin, Bisco, Dr. James Anderson. Devised methods of standard irradiation of polymer-metal composite materials to very high doses of gamma rays.

99. W. L. McLaughlin, Stolle Corp, Dr. B. Johnson. Designed method to test temperature dependence and reproducibility of response of biological indicators (bacillus pumilus) to gamma radiation.

100. W. L. McLaughlin, Radiation Dynamics, Inc., Dr. Marion Strelcyk. Supplied correction data for converting electron beam energy depositer data to correct depth-dose data in totally absorbing calorimeters.

Division 536, Major Consulting and Advisory Services (cont'd.)

101. W. L. McLaughlin, U.S. Dept. of Agriculture, Policy Branch. Dr. Rosanna Morrision. Supplied qualtiy-control data in terms of standardized dosimetry results, in a typical food irradiation process.

102. W. L. McLaughlin, Kiolgray, Inc., Dr. Michael Yang, Dr. Walter Chappas. Solved Bragg-Gray problem in the irradiation of semi-conductor chips for IBM Corp. when held between metal interfaces.

103. W. L. McLaughlin, North American Science Associates, Dr. Scott K. Smith. Designed calibration method for the accurate irradiation of thin micro biological spore strips.

104. W. L. McLaughlin, Michigan Tissue Bank, Dr. Jim Forsell. Design methods for Bragg-Gray cavity theory corrections in the dosimetry for radiation sterilization of various prosthetic devices.

105. W. L. McLaughlin, Atomic Energy of Canada, Ltd., Dr. D. K. Mehta. Design special test and calibration methods for metallic materials irradiations to very high doses of gamma rays.

106. W. L. McLaughlin, NASA, Ames, CA, Dr. J. Goldenrath. Devised method for monitoring halogenated fluids inside pipes near high-dose neutron fields, by liquid chemical dosimetry techniques.

107. W. L. McLaughlin, Rockwell Int., Dr. Brian Oliver. Gave instruction on the use and potential sources of uncertainty in the use of aqueous chemcial dosimeters (e.g. ferrous sulfate, ceric sulfate, etc.

108. W. L. McLaughlin, Nat. Inst. for Pub. Health and Env. Hygiene, Dr. A. M. L. Albers. Design methods for calibration of lyoluminescence dosimeters and temperature dependence studies.

109. W. L. McLaughlin, St. Bartholomew Hospital, Dr. David R. White. Design of bone-equivalent plastic dosimeters for high-dose ranges radiation therapy with photons and electrons.

110. J. S. Pruitt visited the Idaho National Engineering Laboratory, Idaho Falls, to advise on calibration of beta-particle sources, and to provide two such calibrations.

111. R. B. Schwartz consulted with the Battelle Pacific Northwest Laboratory on measurement traceability to NBS of the Department of Energy Laboratories Accreditation Program for Personnel Dosimetry.

Division 536, Major Consulting and Advisory Services (cont'd.)

112. R. B. Schwartz consulted with Argonne National Laboratory on establishing and maintaining traceability to NBS of neutron measurements carried out at Argonne in connection with their NRC contract for checking the accuracy of instruments used by NRC licensees.

113. R. B. Schwartz consulted and advised Los Alamos National Laboratory on the development of a new type of remmeter.

114. J. T. Weaver carried out a site inspection of calibration facilities of Battelle Pacific Northwest Laboratories, Hanford, for the Department of Energy Laboratory Accreditation Program (DOELAP), in November 1984.

JOURNAL EDITORSHIPS

Division 536, Ionizing Radiation

B. M. Coursey, Editor, International Journal of Applied Radiation and Isotopes.

W. B. Mann, Editor, Environment International.

W. B. Mann, Editor, International Journal of Nuclear Medicine and Biology.

W. B. Mann, Editor-in-Chief for North America, International Journal of Applied Radiation and Isotopes.

W. L. McLaughlin, Editor, International Journal of Applied Radiation and Isotopes.

W. L. McLaughlin, Editoral Board, Radiation Physics and Chemistry.

M. G. Simic, International Editorial Board, Free Radicals in Biology and Medicine.

TRIPS SPONSORED BY OTHERS

Division 536, Ionizing Radiation

J. W. Behrens spent a year as a guest scientist with the Commissariart a l'Energie Atomique Centre d'Etudes Bruyeres-le-Chatel, France. (January - December 1984).

M. J. Berger, sponsored by the International Atomic Energy Agency traveled to Rijswijk, the Netherlands to participate in an Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and Related Radiobiology. (September 16-20, 1985)

J. M. Calhoun attended the 1985 Society of Nuclear Medicine Conference and Exhibit in Houston, Texas. (June 1985)

A. D. Carlson, sponsored by the International Atomic Energy Agency (IAEA), traveled to Geel, Belgium to present an invited paper and chair a session at the IAEA Advisory Group Meeting on Nuclear Standard Reference Data. (November 12-16, 1984)

A. D. Carlson, sponsored by the IAEA, traveled to the Nuclear Energy Agency, near Paris, France to discuss collaboration between European and U.S. scientists in the formation of Nuclear Data Files. (November 19, 1984)

R. S. Caswell, sponsored by Columbia University, traveled to Irvington, N.Y. to attend meeting of the Scientific Advisory Committee to the Radiological Research Accelerator Facility (RARAF). (December 17, 1984)

R. S. Caswell, sponsored by the International Commission on Radiation Units and Measurements (ICRU), traveled to Harwell, England to attend annual meeting. (June 1-9, 1985)

J. J. Coyne, sponsored by the International Atomic Energy Agency, traveled to Rijswijk, the Netherlands to participate in an Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and Related Radiobiology and present an invited paper on Secondary Charged Particle Spectra and Kerma Calculations. (September 16-20, 1985)

J. H. Hubbell, sponsored by the Laboratorio de Metrologia dell Radiazioni Ionizzante, traveled to Ferrara and Frascati, Italy to participate as Committee Secretary at a meeting of the International Programme Committee for the Third International Symposium on Radiation Physics, and following that meeting gave an invited seminar in Casaccia, Italy. (September 30 - October 23, 1984)

Division 536, Trips Sponsored by Others (cont'd.)

J. C. Humphreys, sponsored by the FMC Corporation, traveled to and gave talk, "Industrial Radiation Technology", at the FMC Corporation, Santa Clara, CA. (September 26, 1985)

J. M. R. Hutchinson, IAEA sponsored consultation to Comissao Nacional de Energia Nuclear (CNEN), Rio de Janiero, Brazil. (September 1985)

R. Loevinger participated in meetings of the MIRD Committee of the Society of Nuclear Medicine in Las Vegas, Nevada. (December 6-7, 1984)

R. Loevinger participated in meetings of the MIRD Committee of the Society of Nuclear Medicine in San Francisco, California. (July 11-12, 1985)

W. L. McLaughlin, sponsored by the IAEA, attended seminar and gave talk, "Fiber Optics Dosimetry", at the Risø National Laboratory, Denmark. (October 4, 1984)

W. L. McLaughlin, sponsored by Battelle, NW, gave talk, "Dosimetry for Applied Radiation Technologies", at seminar for the Radiological Sciences Dept., Battelle NW, Richland, WA. (November 1, 1984)

W. L. McLaughlin, sponsored by the ICRU, attended the annual meeting of International Commission on Radiation Measurements and Units, Harwell, England. (June 1985)

W. L. McLaughlin, sponsored by the U.S.-Yugoslav Joint Board on Scientific and Technical Cooperation, attended the Seminar on Scientifc Cooperation between NBS and IBK in the 1980-1984 period, Belgrade Yugoslavia. (June 10-11, 1985)

W. L. McLaughlin, sponsored by the U.S.-Yugoslav Joint Board on Scientific and Technical Cooperation, gave talk, "Radiation Dosimetry with Radiochromic Dyes", at the NBS-Boris Kidric Institute Seminar, Boris Kidric Inst. of Nuclear Science, Vinca, Belgrade, Yugoslavia. (June 11, 1985)

W. L. McLaughlin, sponsored by the FDA, gave training course on Validation Procedures and Dosimetry in Routine Industrial Radiation Sterilization at the Ramada Inn, Culver City, CA. (June 26, 1985)

W. L. McLaughlin, sponsored by the FMC Corporation, traveled to and gave talk, "Industrial Radiation Technology", at the FMC Corporation, Santa Clara, CA. (September 26, 1985)

R. B. Schwartz, sponsored by the International Atomic Energy Agency, traveled to Vienna, Austria to finish writing handbook for setting up secondard standard dosimetry laboratories. (November 5-10, 1984)

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Division 536, Trips Sponsored by Others (cont'd.)

R. B. Schwartz, sponsored by the Department of Energy, traveled to Richland, Washington, to advise on making their dosimetry calibration program traceable to NBS. (November 28-30, 1984)

M. G. Simic, sponsored by the Food Processor Institute, gave talk, "Dosimetry of dosage received. Irradiated Foods: A New Business", at the Food Processor Institute, San Francisco, CA. (February 15, 1984)

M. G. Simic, sponsored by Nabisco, gave talk "Fat Oxidation and Antioxidants", at the Nabisco Brands Lipid Symposium, Nabisco, Rochelle Park, NJ. (November 15-16, 1984)

M. G. Simic, sponsored by the American Chemical Society, gave talk, "Antioxidants, Kinetics and Mechanisms," at the Lipid Oxidation Symposium, Miami Beach, FL. (April 28-May 3, 1985)

M. G. Simic and M. Al-Shiekhly, gave talk "Superoxide Radical Generation in Radiation-Induced Autoxidation of Fatty Acids, at the 4th Int. Conf. on "Superoxide and Superoxide Dismutase", Rome, Italy (September 1-6, 1985)

STANDARD REFERENCE MATERIALS

Division 536, Ionizing Radiation

Standards Issued - 1 August 1984 through 31 July 1985

SRM	Radionuclide	Principal Use
4417L-D	Indium-111	Calibration of instruments for activity measurements of radiopharmaceuticals
4410H-J	Technetium-99m	"
4406L-H	Phosphorus-32	"
4420L-B	Lead-203	"
4401L-K	Iodine-131	"
4412L-J	Molybdenum-99	"
4415L-I	Xenon-133	"
4416L-F	Gallium-67	"
4404L-H	Thallium-201	"
4400L-G	Chromium-51	"
4927C	Hydrogen-3 solution	Calibration of liquid scintillation counters
4214B 4408L	Cobalt-57 point source Cobalt-57 solution	Calibration of gamma-ray detectors
4929D	Iron-55 solution	For use in calibrating instruments for measurement of this nuclide in the nuclear fuel cycle
4226B	Nickel-63 solution	"
4276B	Mixed Radionuclide solution antimony-125, europium-154 and europium 155	Gamma ray standard used for the efficieny calibration of x- and γ-ray of detectors

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Division 536, Standard Reference Materials (cont'd.)

SRM	Radionuclide	Principal Use
4950E 4953D	Radium-226 solution Radium-226 solution	Calibration of detectors used for monitoring this nuclide and radon in the environment
4327	Polonium-208 solution	Used as a chemical yield monitor for radiochemical measurements of nuclides in the nuclear fuel cycle
4328	Thorium-229 solution	"
4329	Curium-243 solution	"

CALIBRATION SERVICES PERFORMED

Division 536, Ionizing Radiation

I. Neutron Dosimetry Group

Type of Service	Customer	SP 250	No. of Tests	Income kS
Neutron Source Calibrations	Amersham	8.1B	1	1.70
	Battelle Northwest	8.1C	1	1.68
	Argonne Labs	8.1C	1	1.68
	Lawrence Livermore Spec	8.1B	1	1.50
	Scandia Labs	8.1B	1	1.68
		Total	5	8.24
Thermal Neutron Density Standards	(No calibrations)		0	0.00
		Total	0	0.00
Neutron Personnel Protection Instruments & Filtered Beams	Calvert Cliffs	8.1J	23	5.0
	U.S. Army	8.1H	1	.25
	U.S. Army	8.1J	1	.25
	Omaha Public Power	8.1J	3	.75
	Carolina P&L	8.1J	1	.25
	Northwestern Univ.	8.1J	1	.25
	NRC	8.1J	2	.40
	Eberline Instr. Corp.	8.1H	3	.50
	Barlett Nuclear Corp.	8.1J	4	.80
	WPPSS	8.1J	2	.40
	Illinois Power	8.1J	2	.40
	Eberline Instr. Corp.	8.1J	2	.50
	NSWC	8.1J	6	.80
	Lawrence Livermore Lab	8.1H	1	.25
		Total	52	10.80

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Division 536, Calibration Services Performed (cont'd.)

II. Radioactivity Group

August 1, 1984 to August 1, 1985

	Scheduled Calibrations(1)		Non-scheduled Tests	
	Number of Sources	Total Fee $K	Number of Sources	Total Fee $K
Category				
Alpha-Particle Sources 8.2 H, I, J	34	25.7	3	2.3
Beta-Particle Point Sources and Gases (^{85}Kr) 8.2 P, Q, R	--	--	16	7.8
Gamma-ray Solutions, Point Sources, and Gases (^{133}Xe)	7	7.0	43	30.9
Mixed Radionuclide Sources, Solutions, Point Sources and Gases(2)	--	--	18	22.0
Other Services	--	--	--	3.9
	41	32.7	80	66.9

Footnotes

(1) Multiple sources under one Test Folder are counted as multiple calibrations. Replicate samples are not considered as separate sources. For example, Amersham submits 2 each of 3 different source forms. This is counted as 3 samples.

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Division 536, Calibration Services Performed (cont'd.)

III. Radiation Chemistry & Chemical Dosimetry Group and Electron & Photon Dosimetry Group

Type of Service	Customer Type*	SP 250 Item No.	Number of Calib'ns or Tests	Income
Calibration of x-ray and γ-ray measuring instruments	1-7	8.3A,B.C, D	240	$140k
Irradiation of TL dosimeters	2-6	8.3M,N	110	
Calibration of γ-ray and β-particle sources	2-6	8.4A,E,K	45	$ 6k
Chemical dosimetry measurement assurance service for electron beam	2	8.5A,B,C	125	$ 22
High-dose irradiation	3-7	8.6A,B	565	$ 75k
Dose interpretation	4-7	8.6C	110	
Spectrophot. reading of dosimeters	4-6	8.6D	470	
Irradiat. of TLDs & prep. of units for shipboard measurement	Navy	N.A.	275	$ 65k
Instrument calibration & evaluation	DoE	N.A.	6	$ 9k
Totals			1940	$320k

*Column 2: 1, calibration labs; 2, hospitals; 3, nuclear energy establishments; 4, industry; 5, US government labs; 6, DoD labs; 7, universities.

SPONSORED SEMINARS AND COLLOQUIA

Division 536, Ionizing Radiation

H. Lesiecki, Physikalisch-Technische Bundesanstalt, "Neutron Fields and Neutron Calibrations at PTB", October 23, 1984.

Christian Ballaux, SCK/CEN, Mol, Belgium, "An Overview of Reactor and Waste-Disposal Programs at the Belgian Center for Nuclear Energy, with Some Details of the Radionuclide Metrology Involved", October 25, 1984.

Lennart Lindborg, National Institute of Radiation Protection, Stockholm, Sweden, "Variance-Covariance Measurements. A Technique for Microdosimetry in High-Energy Beams", November 8, 1984.

Richard Sah, Accelerator and Fission Research Division, Lawrence Berkeley Laboratory, "The Design Study for the Advanced Light Source", December 13, 1984.

David Van Holstein and Laurel O. Sillerud, "The Role of Standards in Nuclear Magnetic Resonance (NMR) Imaging", January 31, 1985.

Geoffrey Greene, Quantum Metrology Group, Center for Basic Standards, NBS, "Cold Neutron and Hot Physics: Investigating Fundamental Physics with Low Energy Neutrons", February 28, 1985.

P. J. Matthew, CSIRO, Division of Mineral Physics, Port Melbourne, Australia, "Recent Developments in the Application of Nuclear Techniques in the Mineral Industry in Australia", April 1, 1985.

James W. Behrens, Center for Radiation Research, NBS, "Applied Neutron Physics Projects in France", April 4, 1985.

Horst Klein, Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany, "Neutron Cross Section Measurements at PTB", May 23, 1985.

D. A. Bradley, School of Physics, University of Science of Malaysia, Minden, Penang, Malaysia, "Recent Measurements of Coherent Scattering", May 24, 1985.

J. Trochon, CEA-DAM, Bruyeres-le-Chatel, France, "Cold Fragmentation Measurements using a Very-High-Energy Resolution Ionization Chamber", June 6, 1985.

Albert Lajtai, Central Research Institute for Physics, Hungarian Academy of Sciences, Hungary, "Measurements of Fission Neutron Spectra", June 10, 1985.

TECHNICAL ACTIVITIES

Division 530.01 Nuclear Physics

Task No. 15222 - Nuclear Structure and Standards
Task No. 15223 - Nuclear Radiation Research

The Nuclear Physics Group conducts fundamental research in theoretical nuclear and particle physics, and in experimental studies of intermediate energy electro- and photo-nuclear reactions. This activity is in support of the Center's role in carrying out research necessary for improved understanding of nuclear radiation processes and of the interaction of radiation and particles with matter. This year the formerly separate Nuclear Theory Group (M. Danos, L. C. Maximon, and S. Meshkov) and Nuclear Research Group (experimentalists: W. R. Dodge, E. Hayward, J. W. Lightbody, Jr., and X. K. Maruyama; theorist: J. S. O'Connell) were combined to form the Nuclear Physics Group. There has always been strong overlap of interests and mutual support between the two groups, which has proven beneficial to both. We expect the reorganization will strengthen this tradition and thereby enhance the overall nuclear physics program. There has been no change in emphasis of the separate, experimental and theoretical research activities.

A vital research program is one that addresses priority questions in nuclear theory and experiment and, therefore, requires forefront facilities and a constant exchange of ideas and strong interplay with other laboratories and researchers in the field. The Nuclear Physics Group is planning electro-nuclear coincidence experiments that have been made feasible by the 200 MeV cw racetrack microtron (RTM) now under development at NBS, which will complement the 20 year old 120 MeV electron linac. Nuclear experiments with the linac are being phased out although neutron measurements will continue with this machine. In addition, the group is participating in forefront electro-and photo-nuclear experiments at the higher energy accelerators (MIT and Mainz), and is involved in planning the next generation electron accelerator (CEBAF), aimed at exploring the QCD/nuclear physics interface. The NBS research program profits greatly from the participation of guest workers and collaborators (university faculty and graduate students), who extend our resources and bring in new ideas. We encourage these involvements and, additionally, have an extensive seminar program which brings outside speakers to NBS.

This year many visitors and guest workers contributed to our programs. The list of scientific colleagues who have had extensive visits to NBS include: Miles McCord, Hall Crannell, Dan Sober, Larry Fagg, The Catholic University of America; James O'Brien, Montgomery College; Paul Treado, Georgetown University; Philippe Gouffon, University of Sao Paulo,

Brazil; Johann Rafelski, University of Cape Town, South Africa; Hartmuth Arenhovel, University of Mainz, Mainz, West Germany; M. Sanzone, University of Genoa, Italy; William Briscoe and Francisco Prats, George Washington University; and Bent Schrøder, University of Lund, Sweden.

In addition to guest worker scientists visiting NBS, some members of the Nuclear Physics Group have had extended stays at other nuclear laboratories: L. Maximon and M. Danos, Centre d'Etudes Nucléaire de Saclay, France; E. Hayward, Oxford University Nuclear Physics Laboratory (England); S. Meshkov, Aspen Center for Physics (Aspen, CO) and the Institute for Theoretical Physics (University of California-Santa Barbara); X. K. Maruyama, Naval Postgraduate School (Monterey, CA); and J. S. O'Connell, Lewes Center for Physics (Lewes, DE). These visits provide valuable new insights to our current research and often provide the perspective to plan and direct our future research activities.

In the following sections we outline the groups primary research activities of the past year. This list includes: elementary particle physics, nuclear theory, electromagnetic nuclear physic theory, current experimental activities at NBS and other laboratories, proposals for OA funding of research facilities, and miscellaneous activities.

Elementary Particle Theory. The elementary particle theory program under Dr. S. Meshkov has activities on many fronts. Work on the possible existence of fermions in addition to those of the "standard model," whose gauge group $SU_3^C \times SU_2^C \times U_1^Y$ is broken at low energies to $SU_3^C \times U_1^Y$, was actively pursued. This resulted in two publications in Physical Review D, which showed that without violating low energy bounds given by the $\mu \to e\gamma$ decay rate, significant effects in the decay of the W and Z vector bosons to neutral, left-right symmetric neutral singlets could occur via mixing with the standard model neutrinos. This work was also discussed at numerous seminars at major laboratories.

Work on QCD took a new turn. In addition to a continuation of work on glueballs, Meshkov and collaborators showed that when a recent Monte Carlo Lattice Gauge QCD Potential was confronted with experimental bb and cc quarkonia data, it gave results which, though qualitatively suggestive, were not quantitatively correct. This work, described in a paper submitted to Physics Letters B, led to a more general study of quarkonia in which it was shown by Fishbane, Kaus, and Meshkov that for a separation $r > R_c$, all heavy qq systems can be quantitatively described by a potential characteristic of strings, in particular the Nambu-Gotow string. This work is being continued at the Institute for Theoretical Physics Workshop on Nuclear Chromodynamics at the University of California at Santa Barbara to which Dr. Meshkov was invited and is a participant.

Nuclear Theory. The activities described in this section were carried out by Dr. M. Danos and co-workers. In the past, nuclear forces have been treated by computing a nucleon-nucleon 2-body force in terms of meson exchanges between point nucleons treated in second order perturbation, although it was realized that these nucleons were not point particles but in fact occupied a large part of the volume of nuclei. Now the origin of nuclear forces must be rethought in terms of the underlying quark structure. There are two aspects to this problem. First, the "short-range part" of the interaction must be re-done in terms of explicit quark degrees of freedom. The model available for this treatment is the bag model. However, two-nucleon interactions in this model have six quarks in the bag, and if an exchanged meson is included then there are seven quarks and an antiquark. There are many-body correlations among the quarks. A program to investigate these forces has been started.

To replace the ad hoc boundary conditions of the bag model by a correct description of the hadron-vacuum interface in fact requires a solution, or at least a semi-quantitative understanding, of the confinement problem. It is widely believed that the confinement in QCD, in analogy with superconductivity, results from the existence of a physical vacuum which is removed from the remainder of the spectrum by an energy density gap, which exhibits a Meissner-Ochsenfeld effect, and which can not be described by the methods of perturbative quantum field theory. More particularly, it is believed that these characteristics of the physical vacuum result from the infrared properties of QCD. Utilizing these considerations an attempt is underway to construct a model of the QCD vacuum with the techniques developed in the context of superconductivity theory.

The other aspect concerns the "long-range part" of the interaction, i.e., that part where the microscopic structure of the vertex is unimportant. There the many-body aspects of the system nucleus + mesons have to be accounted for, which are neglected in the presently employed perturbation treatment of the nuclear force. This proper description requires that the nucleus be treated as a relativistic many-body system. A program of such a treatment is underway.

A new emerging field of nuclear physics concerns the question of explicit manifestations of QCD effects in nuclear reactions. A promising approach is the observation of a quark-gluon plasma in the collision of two heavy nuclei. Diverse aspects of this are being explored.

An example of the importance of quarks in the nucleus is a recent study in which experiments at Stanford and by the European muon collaboration have been used to show that between 2 and 10 percent of the quark wave functions occupy the nucleus as a whole rather than are correlated into individual nucleons.

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A different approach to correlations in the nucleus has been the recent study of the Crystalline Nucleus. The nucleus is modelled as a cubic crystal with alpha particles at each lattice point. One alpha particle is excited to its 1^- state and the transmission of this excitation through the crystal lattice is studied. A good fit to the Giant Dipole Resonance for integer values of A/4 is obtained. There are only two parameters in the theory. The one is the excitation energy of the 1^- state of the α particle inside a nucleus and the other is the off-diagonal matrix element for the interaction between nearest neighbors. The good fit is obtained with reasonable values for these parameters.

Electromagnetic Nuclear Physics Theory. The activities in this area are carried out by Drs. L. C. Maximon and J. S. O'Connell. High energy electron scattering and photonuclear reactions continue to be one of the most important probes of nuclei. Sub-nuclear degrees of freedom — involving nucleon resonances, mesons, and quarks — are currently in the forefront of electromagnetic nuclear physics, on a world-wide scale, with major facility expansions to address the new physics questions planned or in the construction phase. In addition to the 200 MeV cw electron accelerator (RTM) under construction at NBS, the MIT pulsed linac is being upgraded to near 1 GeV and there are plans to provide a stretcher ring to convert the pulsed beam to a cw beam. Finally, in this country there is a major DoE project to construct a 4 GeV cw electron facility (CEBAF) in Newport News, VA.

Because of the different types of experiments planned and because of the extended range of energies that will become available, theoretical expressions for the radiation processes will have to be reinvestigated. This includes study of bremsstrahlung processes, bremsstrahlung polarization, radiation tails in electron scattering, and radiative corrections to electron coincidence reactions. Dr. Maximon is preparing an article for Physics Reports on "Tagged Photons; An Analysis of the Bremsstrahlung Cross Section." He is also preparing an article for Physical Review on "Angular Distribution of High Energy Electrons Following Radiation" with A. LePrêtre.

In addition, Dr. Maximon is working with Professor F. Prats of the Nuclear Theory Group at George Washington, on the photodisintegration of few-body systems. This collaboration is an extended activity and has in the past dealt with pionic disintegration of few-body systems as well.

Dr. O'Connell has written a review article with J. Ahrens of Mainz summarizing photon and electron interactions in the delta region (200-600 MeV excitation in nuclei). They discuss the remarkable discovery that all nuclei examined display the same response per nucleon to photon absorption and a universal response to electron scattering in the delta region. The medium modification of the fundamental electromagnetic pion production mechanism from a free nucleon seems to be characteristic of nuclear matter.

Neutrino reactions on nuclei can be calculated in the same framework as electron scattering reactions. Dr. O'Connell has updated an earlier calculation he has done, to try and understand the electron and muon events observed in deep underground water Cerenkov detectors which are used in searches for spontaneous proton decay. The introduction of nucleon binding and treatment of Pauli blocking effects for oxygen led to agreement between the predicted and observed lepton spectra generated by cosmic ray neutrinos. This work was done in collaboration with T. Gaiser of the Bartol Research Foundation.

Finally, in connection with the CEBAF project, Dr. O'Connell has calculated a number of reaction cross sections and coincidence experiment counting rates for GeV electrons on complex nuclei. This effort is part of a study (involving many people in this country and around the world) leading to the design of magnetic spectrometers at the proposed CEBAF accelerator.

Experimental Nuclear Physics. Activities in this area are carried out by Drs. W. R. Dodge, E. Hayward, J. W. Lightbody, Jr., X. K. Maruyama, and J. S. O'Connell. There are two experiments which were recently completed at the linac. Electron scattering measurements (Lightbody, Maruyama, and collaborators) for the proton were performed to extract the root mean square charge radius. The analysis of these data, which are the Ph.D. thesis data of M. McCord of CUA, is in progress. The old proton radius value of 0.80(1) fm is in substantial disagreement with the newer Mainz result of 0.86(1) fm. Our goal is to provide further data to help resolve this issue. The major interest in this subject comes from the field of Lamb shift measurements, where recent work indicates that the agreement with current QED calculations would be improved a great deal with the older 0.80 fm proton radius.

An electrodistintegration experiment on ^{24}Mg has also been completed recently by Dr. W. R. Dodge. This work was in collaboration with members of the Physics Institute of the University of São Paulo, and is the Ph.D. thesis subject for P. Gouffon., This (e,x) experiment examines the alpha decay of a 2^+ level in ^{24}Mg to the ground state of ^{20}Ne. The results are being analyzed and should constitute the first assumption free test of E2 virtual photon theory.

Together with members of an NBS-LUND-UNH-MIT collaboration we initiated a series of coincidence measurements of the $^{238}U(e,e'f)$ cross section at electron energies extending through the quasi-free scattering and delta region (W. R. Dodge, E. Hayward, J. W. Lightbody, Jr., X. K. Maruyama, and J. S. O'Connell). This work was done at the MIT/Bates Linear Accelerator. The experiment measures the time coincidence of the fission process with electron scattering. The fission process coincidence requirement eliminates unwanted radiation processes which encumber the

single arm (e,e') measurements in this energy-loss region and shows interesting new features of the fission and nucleon knockout process. Preliminary results in the delta region show that uranium exhibits the same universal absorption curve as seen in the lighter nuclei ($A < 16$).

In addition to the fission experiment, a 180°(e,e') measurement was performed at Bates (Lightbody and Flanz of MIT). This is the only laboratory in the U.S. with such a 180° scattering capability. The measuremnts were made at low monmentum transfer on the 2_1^+ state of ^{52}Cr to investigate the role of convection currents in nuclear excitations.

The Nuclear Physics group is also involved in other on-going experiments at Bates. The most important of these is the tritium (e,e') measurement scheduled for fall 1985. This represents a major commitment of time by Dodge, Lightbody, and Maruyama. This experiment will demonstrate our fundamental understanding of the three-body system in a region where we expect serious modifications of potential models by non-nucleonic degrees of freedom. This experiment is the highest priority experiment at the Bates laboratory. Dr. Dodge has been an expert adviser on the hazards and use of highly active tritium targets (100 kCu). Dr. Lightbody and Maruyama have participated in an earlier tritium experiment here at NBS.

During this past year and under an agreement between the Naval Postgraduate School and the National Bureau of Standards, X. K. Maruyama was assigned to the Naval Postgraduate School (NPS) as a faculty replacement for the Director of the NPS electron linear accelerator. There he was involved in the study of the Cerenkov radiation phenomenon. In particular, the diffraction aspects of Cerenkov radiation, the coherent effects of electron "bunching," and the harmonic nature of Cerenkov radiation from a periodic electron source were observed at microwave frequencies. Theoretical calculations were done to predict subthreshold Cerenkov radiation and form factor effects which might be important for intense electron beams. The feasibility of observing x-ray Cerenkov radiation at frequencies corresponding to atomic electron absorption edges was investigated.

Proposals to Other Agencies. This year a proposal was submitted to the DoE for construction of a large magnetic spectrometer which would be used with the RTM when it becomes operational. This proposal comes from a consortium of several universities. The magnet optics and all spectrometer details were provided by Ingvar Blomqvist of MIT. E. Hayward led this effort. At this time we have had no official DoE reaction to this proposal.

In addition to the spectrometer proposal, a separate proposal to the DoE to provide minimal equipment for coincidence experiments is being prepared by J. W. Lightbody. In this proposal we ask for funding to purchase solid state telescopes, a scattering chamber, and miscellaneous hardware required to perform prototype (e,e'p) coincidence measurements

with the RTM. For this purpose the (e,x) spectrometer is being converted (by addition of a drift chamber presently under construction) to application as an electron spectrometer.

Miscellaneous Activities. During this year Dr. Hayward prepared an extensive review paper on virtual photon theory and electrodisintegration experiments. She delivered this work at the Verona summer school on Intermediate Energy Nuclear Physics. In addition to this, she is actively involved in electrodisintegration experiments on ^{90}Zr and ^{92}Zr (Dodge and Hayward) and together with Dodge is working on a very fundamental aspect of current conservation known as Siegert's Theorem, in which the relation between Coulomb and transverse electromagnetic nuclear excitation can be studied. Dr. Hayward is also participating in photon scattering experiments at Mainz using their operating cw accelerator as well as their pulsed linac.

Drs. Dodge and O'Connell have also been working on development of detectors for use in a polarized electron scattering coincidence measurement at Bates. This measurement will be the first of its kind and will access a heretofore inaccessible nuclear structure function. They will use the reaction, (e,e'p), to look at the knockout protons with a high purity germanium detector telescope. This type detector has broad application in other coincidence experiments, and represents in some cases a much less expensive approach than through the use of large and extremely expensive magnetic spectrometers.

Finally, a number of people in the Group are involved in the planning of CEBAF, the future 4 GeV national electron facility for nuclear physics. Lightbody has chaired the Magnetic Spectrometer Working Group and worked on (e,e'2N) and other reaction calculations for planning the basic experimental program. O'Connell has made many detailed calculations of nucleon knockout, pion production, and delta production processes for this same purpose, and is involved in summary activities of the summer long CEBAF Summer Study Group.

We feel that the Nuclear Physics program represents long range NBS goals in nuclear research, and there is a growing vitality from measured involvement with the larger nuclear research community. The theoretical efforts cover the full spectrum of current interest in nuclear research. The experimental effort represents a healthy balance between in-house research and research at other facilities.

BEST AVAILABLE

INVITED TALKS

Division 530.01 Nuclear Physics

Danos, M., "Relativity in Terrestrial Physics: Why Bother?," Naval Research Laboratory, Washington, D.C., January 10, 1985.

Dodge, W. R., "Virtual Photons in Theory and Experiment," Conference on the Applications of Accelerators in Research and Industry; Denton, Texas; November 13, 1984.

Dodge, W. R., "Measurement of the Fifth Response Function in the ($\vec{e}$,e'x) Cross Section," CNFQ, Rio de Janeiro, Brazil; November 20, 1984.

Hayward, E., "Photon Absorption and Scattering in the Δ-Resonance Region," MIT, Boston, MA, November 1984.

Hayward, E., "High Energy Photon Scattering Experiments," Photon Scattering Workshop, Brookhaven National Laboratory, Upton (L.I.) NY, November 25, 1984.

Hayward, E., "Electrodisintegration Experiments and Virtual Photon Spectra," International School of Intermediate Energy Nuclear Physics, Verona, Italy, June 1985.

Hayward, E., "NBS Electrodisintegration Experiment," University of Genoa, Genoa, Italy, June 1985.

Lightbody, J. W., Jr., "Experiments at the Continuous Electron Beam Accelerator Facility," Memphis Meeting of the American Physical Society (Division of Nuclear Physics), Memphis, TN, October 26, 1984.

Lightbody, J. W., Jr., "Perspectives in Intermediate Energy Nuclear Physics," Conf. on Electromagnetic Interactions of Nuclei at Low and Medium Energies, Moscow, USSR, December 10-12, 1984.

Lightbody, J. W., Jr., "Electronuclear Studies at NBS," Univeristy of Mainz, Mainz, Germany, December 1984.

Lightbody, J. W., Jr., "Nuclear Research with the RTM," University of Lund, Lund, Sweden, December 1984.

Lightbody, J. W., Jr., "Summary: Moscow Conference on Intermediate Energy Nuclear Physics," George Washington University, Washington, D.C., February 11, 1985.

Division 530.01, Invited Talks (Cont'd)

Lightbody, J. W., Jr., "Current Status and Issues Facing the Magnetic Spectrometer Working Group," CEBAF 1985 Summer Workshop, Newport News, VA, June 1985.

Lightbody, J. W., Jr., "Summary: Magnetic Spectrometer Working Group," CEBAF 1985 Summer Workshop, Newport News, VA, June 1985.

Lightbody, J. W., Jr., "Physics Questions Facing CEBAF," Lewis Center for Physics, Lewes, DE, June 1985.

Lightbody, J. W., Jr., "Two-Nucleon Knockout Reactions ," CEBAF 1985 Summer Workshop, Newport News, VA, July 1985.

Lightbody, J. W., Jr., "Nuclear Research with the NBS rtm," NBS Gaithersburg, MD, August 1985.

Maruyama, X. K., "Cerenkov Radiation Research," Center for Radiation Research, NBS, Gaithersburg, MD, March 7, 1985.

Maruyama, X. K., "Structure Factors in Cerenkov Radiation," Naval Postgraduate School, Monterey, CA, March 29, 1985.

Maruyama, X. K., "Microwave Cerenkov Radiation," San Jose State University, San Jose, CA, April 1985.

Maruyama, X. K., "Cerenkov Radiation Research at the Naval Postgraduate School," Electrotechnical Laboratory, Tsukuba, Japan, May 28, 1985.

Maximon, L. C., "High Energy Electron Scattering - Theoretical Corrections to Experimental Data," Georege Washington University, Washington, D.C., February 25, 1985.

Maximon, L. C., "The Radiative Tail in High Energy Electron-Nucleus Scattering," The XXV Cracow School of Theoretical Physics, Zakopane, Poland, June 112, 1985.

Meshkov, S., "A New Resonance at 8.3 GeV - Interesting?" Center for Radiation Research, NBS, Gaithersburg, MD, October 11, 1984.

Meshkov, S., "Extensions of the Standard Model," Los Alamos National Laboratory, Los Alamos, NM, November 15, 1984.

Meshkov, S., "Chiral Fermions," University of Wisconsin, Madison, WI, May 6, 1985.

Division 530.01, Invited Talks (Cont'd)

Meshkov, S., "Chiral Fermions," University of Cincinnati, Cincinnati, OH, May 9, 1985.

Meshkov, S., "Glueballs," University of Cincinnati, Cincinnati, OH, May 9, 1985.

O'Connell, J. S., "Neutrino-Nucleus Reactions," University of Wisconsin - Workshop on Neutrino Interactions, Madison, WI, November 28, 1984.

O'Connell, J. S., "Polarized Electron Scattering on Nuclei," Bates Linear Accelerator Center, Middleton, MA, December 13, 1984.

O'Connell, J. S., "Electromagnetic Reactions in the Delta Region," University of Virginia, Charlottesville, VA, January 22, 1985.

O'Connell, J. S., "Electromagnetic Reactions in the Delta Region," University of Illinois, Champaign, IL, March 6, 1985.

O'Connell, J. S., "New Fission Results," Lewes Center for Physics, DE, June 18, 1985.

O'Connell, J. S., "Nucleon Production by GeV Electrons," CEBAF 1985 Summer Workshop, Newport News, VA, August 16, 1985.

PUBLICATIONS

Division 530.01 Nuclear Physics

Adler, J. O., Blomqvist, K. I., Calarco, J. R., O'Connell, J. S., Connelly, J., Dodge, W. R., Hansen, K., Hersman, W., Lightbody, J. W. Jr., Nilsson, D., Sandell, A., and Schrøder, B., "A Study of the Reaction $^{238}U(e,e'f)$ in the Delta Region with 720 MeV Electrons," Proc. Nuclear Physics with Electromagnetic Probes, Paris, France, July 1985.

Ahrens, J., and O'Connell, J. S., "Mass Independence of the Electromagnetic Nuclear Response in the Delta Region," Comments on Nuclear and Particle Physics, 1985.

Beck, D. H., Kowalski, S. B., Schulze, M. E., Turchinetz, W. E., Lightbody, J. W., Jr., Maruyama, X. K., Stapor, W. J., Caplan, H. S., Retzlaff, G. A., Skopik, D. M., Galoski, R., Tritium Form Factor at Low q, Phys. Rev. C, 30 (1984).

M. Danos, V. Gillet, and M. Cauvin, Methods in Relativistic Nuclear Physics, North Holland (Amsterdam, Oxford, New York, Tokyo) 1984.

M. Danos and A. Johnson, Non-Observability of Non-Exponential Decay, Phys. Rev. D30, 2692 (1984).

M. Danos and J. Rafelski, Pocketbook of Mathematical Functions, Harri Deutsch (Thun, Frankfurt/Main) 1984.

Delsanto, P. P., Biedenharn, L. C., and Danos, M., Interaction of Quasi-Closed Channels with Open-Channel Continuum, Nuovo Cimento Lett. 42, 59 (1985).

Dodge, W. R., "Virtual Photons in Theory and Experiment," Nucl. Instr. Methods in Physics Research B10/11, 432 (1985).

Dodge, W. R., "An Estimate of Proton Yield from Quasi-Elastic Scattering on ^{16}O at an Incident Energy of 800 MeV," Proc. Nuclear Physics with Electromagnetic Probes; Paris, France, July 1985.

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Lane, K., Meshkov, S., and Wilczek, F., "Possible Interpretation of a New Resonance at 8.3 GeV," Phys. Rev. Lett. 53, 1718 (1984).

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Martins, M. N., Hayward, E., Lamaze, G., Maruyama, X. K., Schima, F. J., Experimental Test of the Bremsstrahlung Cross Section, 30 (1984).

Maruyama, X. K., and Zurey, E. C., Jr., A Flash X-Ray Facility for the Naval Postgraduate School, Naval Postgraduate School Technical Report No. 61-85-004, June 1985.

Maximon, L. C. and LePretre, A., Angular Distribution of High Energy Electrons Following Radiation, NBSIR 84-2854 (1985).

O'Connell, J. S., Dodge, W. R., Lightbody, J. W., Jr., Maruyama, X. K., Adler, J. O., Hansen, K., Schroder, B., Bernstein, A. M., Blomqvist, K. I., Cottman, B. H., Comuzzi, J. J., Miskimen, R. A., Quinn, B. P., Electron Scattering in the Excitation Region of the Delta Resonance on Nuclei with A=1 to 16, Phys. Rev. Lett., 53, No. 17 (1984).

O'Connell, J. S., "Nuclear Production by GeV Electrons," Proc. CEBAF Summer Study, September 1985.

J. Rafelski and M. Danos, Nuclear Matter Under Extreme Conditions in Hadrons and Heavy Ions, Proc. Summer School at University of Cape Town, January 11-27, 1984. Edited by W. D. Heiss, Lecture Notes in Physics, 231, Springer-Verlag, Berlin, Heidelberg, New York, Tokyo (1984).

PUBLICATIONS IN PREPARATION

Division 530, Nuclear Physics

M. Danos and J. Rafelski, Formation Conditions of Quark-Gluon Plasma a Central Rapidity, Physical Review (to be published).

Danos, M. and Johnson, A., "Quarks in the Nuclear Ground State" (submitted to J. Phys. G.)

Danos, M., Kohmura, T., Suzuki, T., Cauvin, M., and Gillet, V., "Shell Model Interaction Energies in a Relativistic Hamiltonian Formulation," (accepted for publication in Nuclear Physics.)

Dodge, W. R., Hayward, E., Martins, N. M., and Wolynec, E., "(e,p) and (e,α) Reactions in ^{90}Zr and ^{92}Zr," (to be published in Phys. Rev. C.)

Dodge, W. R. and Hayward, E., "Siegerts Theorem and Nuclear Electrodisintegration," (submitted to Phys. Rev.)

Jacobs, S., Olsson, M. G., Kaus, P., and Meshkov, S., "Direct Test of a Monte Carlo Lattice Gauge Heavy Quark Potential," (submitted to Phys. Lett. B.)

Maruyama, X. K., Neighbours, J. R., Buskirk, F. R., Electron Beam Bunch Profile Determination Through Cerenkov Radiation, IEEE Transactions in Nuclear Science (in press).

Maruyama, X. K., Neighbours, J. R., Buskirk, F. R., Snyder, D. D., Vujakllja, M., Bruce, R. G., Observation of Microwave Cerenkov Radiation as a Diffraction Pattern, J. Appl. Phys. (to be submitted).

Neighbours, J. R., Maruyama, X. K., Onset of Cerenkov Radiation, Proceedings of the SDIO/DARPA/Services Annual Propagation Review 1985 (in press).

Neighbours, J. R., Buskirk, F. R., Maruyama, X. K., Emission Threshold for Cerenkov Radiationk J. Appl. Phys. (submitted).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 530.01 Nuclear Physics

Danos, M.

Chairman, NBS Colloquium Committee

Dodge, W. R.

Member, MIT/Bates Accelerator Laboratory Hazards Committee

Hayward, E.

Chairman, Division of Nuclear Physics of the American Physical Society.

Member, Program Committee, Division of Nuclear Physics of the Americal Physical Society.

Member, Board of Trustees, Southeastern Universities Research Association (SURA).

Member, SIRA Subcommittee on Public Information.

Chairman, Nominating Committee, Continuous Electron Beam Accelerator Facility (CEBAF) User Group.

Member, NML Women's Personnel Committee.

Lightbody, J. W., Jr.

Chairman, National Advisory Board, Continuous Electron Beam Accelerator Facility, Newport News, VA.

Member, Program Advisor, Committee, MIT/Bates Linear Accelerator.

Member, Technical Advisory Committee, MIT/Bates Linear Accelerator.

Member, Nominating Committee, Bates Linear Accelerator User Group.

Member, Board of Directors, CEBAF Users Group.

Member, Program Committee, Division of Nuclear Physics of the APS.

Chairman, Magnetic Spectrometer Working Group, CEBAF.

Division 530.01 Technical and Professional Committee Participation and Leadership (cont'd)

Member, Program Advisory Committee, Saskatchewan Linear Accelerator Laboratory

Maruyama, X. K.

Chairman, Radiological Safety and Isotopes Committee, Naval Postgraduate School, Monterey, CA.

Member, Minority Advisory Committee, National Measurement Laboratory, National Bureau of Standards.

Meshkov, S.

Member, Board of Advisors, Aspen Center for Physics, Aspen, CO.

Member, Board of Advisors, Lewes Center for Physics, Lewes, DE.

Member, LAMPF II Planning Committee, Los Alamos, NM.

Member, Organizing Committee, Aspen Winter Physics Conference, Aspen, CO.

Member, Program Committee, Aspen Center for Physics, Aspen, CO.

Member, Attendee Selection Committee, Aspen Center for Physics, Aspen, CO.

O'Connell, J. S.

Member, Nominating Committee, APS Division of Nuclear Physics.

Member, Directors Advisory Committee, MIT/Bates Linear Accelerator.

Vice-Chairman, Bates Accelerator User Group.

Member, Organizing Committee, Nation Nuclear Physics Summer School, Georgetown University.

JOURNAL EDITORSHIPS

Division 530.01 Nuclear Physics

O'Connell, J. S, Member, Editorial Board, Physical Review C (Nuclear Physics).

TRIPS SPONSORED BY OTHERS

Division 530.01 Nuclear Physics

M. Danos, Trip to Saclay Center for Nuclear Studies to work on joint research, sponsored by Saclay, Spring, 1985.

W. R. Dodge, Two trips to MIT sponsored by the MIT/Bates Accelerator Laboratory, to attend meetings of the Tritium Hazards Committee, January and September 1985.

E. Hayward, Trip to MIT to give seminar, sponsored by MIT, November 1985.

E. Hayward, Travel expenses to the Nuclear Physics Laboratory of Oxford University, Oxford, Endland paid by Oxford, July 1985.

J. W. Lightbody, Jr., Traveled to MIT to attend MIT/Bates Technical Advisory Panel Meeting, trip sponsored by MIT, January 1985.

J. W. Lightbody, Jr., Traveled to Moscow, USSR, to give invited talk, expenses in the Soviet Union paid by the Soviet Government, December 1985.

J. W. Lightbody, Jr., Traveled to CEBAF (Newport News, VA) to attend conference and give two talks, sponsored by CEBAF, June 3-7, 1985.

X. K. Maruyama Traveled to the Naval Postgraduate School for temporary assignment (research, teaching, and supervisory roles) sponsored by the Naval Postgraduate School, Monterey, California (August 1984 - September 1985).

X. K. Maruyama attended and presented a paper at the 1985 Accelerator Conference in Vancouver, B.C. (May 13-16, 1985), sponsored by NPS.

X. K. Maruyama attended a workshop on the Advanced Test Accelerator, Lawrence Livermore National Laboratory, Livermore, CA. (April 8, 1985), sponsored by NPS.

X. K. Maruyama traveled to the Linac at the Electrotechnical Laboratory, Tsukuba, Japan and presented a talk (May 28, 1985).

X. K. Maruyama visited the Naval Surface Weapons Center, White Oak, MD; Harry Diamond Laboratory, Silver Spring, MD; Naval Research Laboratory, Washington, D.C.; and Physics International, San Leandro, CA, to confer about flash x-ray machine for the Naval Postgraduate School (March 1985), sponsored by NPS.

Division 530.01, Trips Sponsored by Others (cont'd)

L. C. Maximon, Traveled to the Saclay Accelerator Laboratory, Paris France, Expenses in France paid by Saclay; April 1985.

L. C. Maximon, Trip to Poland sponsored by Polish government, to lecture at Nuclear Physics Summer School, June 12, 1985.

S. Meshkov, Trip to Los Alamos National Laboratory to give a theoretical seminar was sponsored by Los Alamos, November 15, 1984.

S. Meshkov, Trip to Caltech to work on collaborative research sponsored by Caltech (March 3 - April 22, 1985).

S. Meshkov, Trip to University of Wisconsin Elementary Particle Conference and give a seminar was sponsored by the University of Wisconsin (May 1985).

S. Meshkov, Trip to University of Cincinnati to give a theoretical seminar was sponsored by the University of Cincinnati (May 9, 1985).

S. Meshkov, Trip to the Institute for Theoretical Physics at U.C. Santa Barbara, to work on collaborative research was sponsored by UCSB.

J. S. O'Connell, Trip to University of Virginia to give seminar sponsored by University of Virginia, January 22-23, 1985.

J. S. O'Connell, Trip to University of Illinois to give seminar sponsored University of Illinois, March 6-7, 1985.

J. S. O'Connell, Trip to CEBAF (newport News, VA) to work on physics program of CEBAF sponsored by CEBAF; August 4-17, 1985.

SPONSORED SEMINARS AND COLLOQUIA

Division 530.01, Nuclear Physics

Marcella Sanzone, Instituto di Scienze Fisiche, Universitàdi Genova, Genova, Italy, "Deuteron Photodisintegration Between 100 and 260 MeV", October 4, 1984.

Richard Deslattes, Center for Basic Standards, NBS, "Second Generation Lamb Shift Measurements", October 11, 1984.

Sydney Meshkov, Center for Radiation Research, NBS, "A New Resonance at 3.3 GeV--Interesting?", October 18, 1984.

David Dowell, Brookhaven National Laboratory, "Proton Capture to Giant Resonances Built on Highly Excited States", October 30, 1984.

Masami Yamada, Waseda University, Tokyo, Japan, "Partly Frozen Liquid-Drop Model of Atomic Nuclei", November 21, 1984.

Moshe Gai, Yale University, "Dipole Collectivity in Nuclei", November 30, 1984.

Richard Pehl, Lawrence Berkeley Laboratory, "Double Beta Decay", December 18, 1984.

Peter Zimmerman, Louisiana State University, "A Physicist Looks at Arms Control", January 24, 1985.

Barry Berman, George Washington University, "Channeling Radiation", February 7, 1985.

Thomas Gaisser, Bartol Research Foundation-Franklin Institute, University of Delaware, "Cosmic Ray Cascades in the Atmosphere", February 21, 1985.

X. K. Maruyama, Center for Radiation Research and Naval Postgraduate School, NBS, "Microwave Cherenkov Radiation", March 7, 1985.

Malcolm J. Cooper, University of Warwick, United Kingdom, "Who Discovered the Compton Effect?", March 28, 1985.

E. G. Fuller, Center for Radiation Research, NBS, "Review of Photonuclear Cross-Sections for p-Shell Nuclei", March 21, 1985.

Paul Stoler, Rensselaer Polytechnic Institute, "Photopion Production in p-Shell Nuclei", April 11, 1985.

Division 532, Sponsored Seminars and Colloquia (cont'd.)

Branka Antolkovic, Institut Ruder Boskovic, Zagreb, Yugoslavia, "Nultiparticle Breakup of Light Nuclear Systems", May 20, 1985.

Michael Weyrauch, University of Virginia, Charlottesville, VA, "Non-Nucleon Degrees of Freedom in Nuclear Photon Scattering", May 28, 1985.

W. Greiner, University of Frankfurt, West Germany, "Puzzles in High Z Atomic and Nuclear Physics", July 24, 1985.

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during Fiscal Year 1985 in the NBS Center for Radiation Research. These activities fall in the areas of atomic and plasma radiation, radiation physics, radiometric physics, radiation sources and instrumentation, ionizing radiation, and nuclear physics.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Atomic radiation, ionizing radiation; measurement support; nuclear radiation; plasma radiation; radiation instrumentation, radiation measurements; radiation physics, radiation sources; radiometric physics.

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